Analysis of Some Aspects of Photosynthetic Activity in the Most Polluted Stretch of River Ganga

By
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ENVIRONMENTAL ENGINEERING AND MANAGEMENT PROGRAMME
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Analysis of Some Aspects of Photosynthetic Activity in the Most Polluted Stretch of River Ganga

A Thesis Submitted
in Partial Fulfillment of the Requirements
for the Degree of

Master of Technology

By

Ajay Veer Singh Yadav

To the

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Ajay Veer Singh Yadav

Contents

List of Figures

List of Tables

Abstract

River Ganga has been receiving several tones of organic, nutrient and other toxic metal and non-metal loads from several point as well as diffused sources of pollution along its 2,525 km course from Gangotri to Bay of Bengal. Despite this the dissolved oxygen (DO) levels in the river have not deteriorated significantly at most of the locations. It has been postulated that photosynthetic activity, particularly algal activity, plays an important role in the maintenance of DO levels in the river water. As such the major thrust in the present research was on examination of the trend in water quality parameters which may have influenced the photosynthetic activity and to analyse some aspects of the photosynthetic activity based on the limited water quality survey. The most polluted stretch of the river from Fatehgarah to down stream of Kanpur spanning over a length of about 200 km in the state of Uttar Pradesh, designated as Kannauj-Kanpur stretch, was selected. Water quality survey programme over a period of one year at six selected sites along with some laboratory experiments were carried out to confirm and assess some aspects of photosynthetic activity. The water quality monitoring results of the present study were merged with the available data from previous monitoring studies in order to study the trend in water quality parameters. The results indicate that (i) BOD and DO levels have increased in the entire stretch except at one of the sites, namely Jajmau at downstream of Kanpur, where anaerobically treated tannery and domestic wastewaters are being discharged, (ii) nitrogen levels in the entire stretch have increased, (iii) DO and alkalinity levels show diurnal variations at all selected sites, (iv) chlorophyll-a levels and oxygen production rates due to photosynthesis appear to be positively influenced by phosphate levels in the river water, and (v) the low levels of DO at Jajmau appears to be due to instantaneous oxygen demand by anaerobically treated wastewaters.

Keywords

The River Ganga, Ganga Action Plan, River Action Plan, River Water Quality, Nutrient Levels, Photosynthesis in Rivers, Chlorophyll-a Levels.

1 Introduction

The Ganga river is considered to be the holiest river in India with religious importance. It originates at Gaumukh from the icy Glacial deposits of Gangotri as "Bhagirathi" at an altitude of about 4000 m in the Himalayas at latitude 31^0N and longitude 7^0E. It is joined by Alaknanda at Deoprayag and the combined stream under the name Ganga flowing through mountainous region debouches into the plains at Rishikesh. It is joined by a large number of tributaries on both banks in the course of its total run of 2525 km before it falls into Bay of Bengal. The important tributaries are the Yamuna, Ramganga, Gomti, Ghaghra, Son, Gandak, Kosi and Mahananda. There are about 692 towns and cities distributed over the eight Gangetic States. Out of these, some 563, representing over 68.7 percent of total basin urban population are concentrated in three alluvial states only: UP, Bihar and West Bengal. Some of the important cities on the banks of river are Haridwar, Kanpur, Allahbad, Varanasi and Patna. River Ganga serves as an important source of water supply as well as sink to the waste generated by millions of people and industries, which flourish in its basin.

Gangetic plain is one of the most irrigated basins in the world and its 80 per cent population is rural. Agricultural runoffs laden with pesticides, fertilizers and cattle wastes find their way to river. Urban sector on the other hand, in spite of representing only 20 percent population contributes much higher to the river pollution. Hazardous effluents from chemical industries and tanneries add toxicity to water and effluents from distillery, sugar mills along with urban domestic waste adds to the organic load of river. Due to

religious tradition people bring dead bodies of their kin to ghats for last rites and increasing cost of firewood compel some of them to leave the unburnt or half burnt bodies along river-side, which hosts numerous bacterial colonies. Although devout Hindus still pay obeisance to this holiest of rivers, it has now become almost synonymous with pollution and filth in several stretches.

As a result of the activities along the riverside, water quantity as well as quality in the river has declined over the years. A comprehensive examination of the river water quality studies carried out by various agencies over the past 2-3 decades indicate that the water quality is insignificantly different from Rishikesh to Calcutta except in the stretch Kannauj to Kanpur. This stretch of river Ganga is considered to be the most polluted one. In this stretch, highly polluted Kali meets Ganga at Kannauj and some untrapped huge drains join the river, thereby adding significantly to the BOD load. Hundreds of tanneries and few textile industries too add to the pollution load in this stretch. People, whose religious sentiments are attached to river have resentment, as for them the river has degraded aesthetically.

To bring back the glory of river and harness its resources, Government of India came up with Ganga Action Plan (GAP). The emphasis in GAP scheme was to reduce the organic load on the river through interception, diversion and treatment of wastewater reaching the river and maintain the BOD and DO levels of river within the acceptable limits. Crores of rupees were spent in GAP phase I, and authorities claim to achieve significant improvement in the DO and BOD levels. However these claims have been challenged by several other agencies and the BOD values in pre and post GAP phase I appear to be insignificantly altered. Also, the significance of reduction in BOD loads through GAP

schemes when DO levels are being maintained high, despite the fact that actual quantity of organic matter flowing into the river over the years has increased, is being questioned.

In GAP the stress is laid on river water quality from the domestic use viewpoint only i.e. either as a source of raw water for domestic supplies or the bathing from religious angle. The significance of river ecology has not been addressed adequately. One of the important aspects from this end is the photosynthetic activity in the river Ganga. It has been postulated that photosynthetic activity plays an important role in maintaining high levels of DO in the rivers and as a result can assimilate high organic loads without significantly affecting the river condition. However, several issues such as oxygenation rates due to photosynthesis, factors and/or river water quality influencing photosynthetic activity in the river, long-term changes in the photosynthetic activity in the river and its impact on the overall river ecology need to be studied. It is to address some of these issues that the present research was undertaken.

2 Literature Review

2.1 Scope

India has recently crossed the 1 billion mark in population. With increasing population and urbanization the water withdrawal rates and the organic and nutrient loading on aquatic systems has increased manifold. Nitrogen and phosphate, which are the potential nutrients for aquatic life (mainly algae), are found in abundance in most of the surface water bodies. Increased nutrient levels enhance algal growth, and hence the photosynthetic activity in river. Algal growth and photosynthetic activity play an important role in altering the waste assimilative capacity, maintenance of dissolved oxygen levels in river water and impact on river ecology. River action plans, with the objective to clean and bring back the virginity of river systems, have been formulated and launched by the Government of India. There are, however, several issues raised in the implementation of river action plans in general and the Ganga action plan in particular. Some of the issues and concerns relate to photosynthetic activity in the river Ganga. A lot of literature is available on photosynthesis, eutrophication of water bodies, and river Ganga. However, the scope of the present review is limited to photosynthetic activity in river Ganga.

2.2 Photosynthesis in Aquatic Systems

Temperature, turbulence, water transparency, amount of incident solar radiations, organic matter concentration, nutrient levels and presence of toxic metal and non-metal substances in river water are some of the important factors which govern the

photosynthetic activity in aquatic systems in general and rivers in particular (Uhlmann, 1979). Literature is flooded with information on eutrophication and photosynthesis in various rivers. The main cause for increased photosynthetic activity is the increased levels of nutrients namely, nitrogen and phosphorous (Lijklema, 1995). The photosynthetic activity in several rivers has been controlled through control of nitrogen and phosphorous loading on the rivers (Forsberg, 1998). Nitrogen has been controlled through biological treatment of wastewaters using nitrification – denitrification processes (Benefield and Randall, 1980). However, removal of phosphorous through available biological and non-biological processes is very limited and economically infeasible (Gerdes and Kunst, 1998). As such emphasis is given on ban of phosphorous containing substances like detergents (Forsberg, 1998). Most of the studies related to eutrophication of rivers suggest phosphorous as the limiting nutrient (Rosensteel and Strom, 1991). A lot of information is available on various types of algae and other aquatic plants present in the river systems depending upon the level of nutrients, organic matter concentration, and their role in overall ecology of the river system (Brooks, 1971). However, very limited and scattered information is available with respect to photosynthesis and eutrophication in river Ganga. Recently some studies have been carried out which emphasize on the role of photosynthetic activity in the river Ganga. (Gupta, 2000; Pooja Anand and Agarwal, 2000).

2.3 River Water Quality

Several studies have been carried out by various agencies over the past 3-4 decades on river water quality monitoring. For example, while monitoring river Ganga from Rishikesh to Varanasi, Bhargava (1977) pointed out Kannauj to Kanpur and then

Varanasi as the most polluted stretches of river Ganga. At Kanpur, Saxena *et al.* (1966) carried out the systematic survey of the physical, chemical and bacteriological quality of Ganga river water. The survey revealed that quality of water was reasonably satisfactory at city's water intake at Bhaironghat pumping station but deteriorated in dredge channel after receiving pollution from city and condition was worse at Jajmau where untreated tannery effluent was mixed with the river. They recommended setting up of treatment plants by various pollution-generating industries. Kashiprasad (1977) reported some improvement in water quality parameters such as BOD, DO, total phosphate and nitrate as compared to the previous study by Saxena *et al.* (1966).

Seasonal trends in river water quality parameters at Varanasi were studied by Laxminarayan (1965). He related water quality with periodicity of some aquatic life forms. Agarwal *et al.* (1976) reported high values of MPN and few pathogenic organisms like *V. cholera*, and organisms from Salmonella and Shigella group.

Despite high organic pollution load in River Ganga, it maintains the low BOD levels after covering some distance downstream (Bhargava, 1977). Pavoni *et al.* (1972) suggest bioflocculation mechanism in which the exocellular polymers excreted by the various species of bacteria in the endogenous phase act as excellent coagulants. These coagulants are reported to be effective in flocculating the finely divided inorganic and organic matter and thereby removing them through settling to the bed.

In order to improve the quality of Ganga water, Ganga Ation Plan (GAP) was initiated in 1985 and National River Conservation Directorate (NRCD) was set up. It

started the programme of monitoring the river by various agencies and significant improvement in Ganga river water quality in terms of DO and BOD was reported (NRCD, 1999). However, the effectiveness of GAP schemes in improving the quality of river water in terms of DO and BOD has been questioned (Gupta, 2000). It has been postulated that the maintenance of high DO levels in the river is due to significant photosynthetic activity and not due to the reduction of organic load. DO levels above the saturation DO levels have been reported (Pooja Ananad and Agarwal, 2000). While the aforementioned literature reports suggest significance of photosynthetic activity in the river, no attempt has been made to analyse the trends in water quality parameters. Also no literature information could be traced which report direct studies on the photosynthetic activity in the river

2.4 River Biology

Abundance of nutrients like N and P and suitable temperature support the aquatic life. Presence of aquatic life, particularly phytoplankton affects the water quality and is in turn affected by pollution loads. Several studies have been done on the presence and periodicity of phytoplanktons in river Ganga. Chlorophyceae, Bacillariophyceae, Cyanophyceae and Euglenophyceae are the prominent groups of algae present at almost all sites of river Ganga (Khanna, 1993). Vandana and Shukla (1995) confirmed their presence in the stretch Bithoor to Nanamau at Kanpur, UP.

Phytoplankton produces oxygen due to photosynthesis in presence of sunlight and consumes it in dark due to respiration. If population of phytoplankton is large, the oxygen depletes to large extent and threatens other aquatic life like zooplanktons and fishes in night hours. Agarwal (1995) reported the decline in population of Cirrhinus

Regale (Mirka) and Labeo Rohita (Rohu). Platanista Gangetica (Ganga river Dolphin) is another endangered species of river Ganga. Although, reason for their decline has not been cited, but deficiency in oxygen levels at night may be one of the reasons.

Some of the algae, like Cyanobacteria, if present in water bodies are toxic. They have some advantages over non-toxic algal species. In calm waters the gas vacuolated Cyanobacteria maintain their position in photic zone and continue growth while the non-gas vacuolated algae can't maintain their position in water column and sink from the photic zone (stop photosynthesizing) to the sediments (Fallowfield, 1990). These algae are toxic to human beings on consumption of contaminated seafood products. Several fatal illness caused are Amnesic Shellfish Poisoning, Ciguatera Fish Poisoning, Neurotoxic Shellfish Poisoning, etc.

Temperature, turbulence, turbidity, organic waste and DO are the main factors that influence the Cyanophyceae population in river Ganga (Sabat and Nayar, 1990). Temperature range between 28^0C to 30^0C is most suitable for most of the Cyanophycean growth. Temperature higher than this usually leads to a decline in their population. The total number of phytoplankton in river at Varanasi and their seasonal variation is given in Table 2.1.

Laxminarayan (1965) investigated various algal groups and found that the population of Bacillariophyceae and Myxophyceae was higher in the months of March and December. The population of Myxophyceae was observed to be minimum in April. The Number of Chlorophyceae gradually increases from March to June and suddenly

falls to minimum in rainy season. Euglenineae was reported maximum in March and showed abrupt fall in May.

Experimental studies on the mineral nutrition of algae in general and phytoplankton forms in particular suggested the essential nutrients for algal growth to be nitrogen, phosphorous, sulphur, K, Ca, Mg, Fe and silica besides the micronutrients (Krauss, 1953, 1956; Ketchum, 1954). Since most of these nutrients are present in river Ganga, Laxminarayan (1965) studied their utilization by phytoplankton population. Depletion in phosphate and various forms of nitrogen as a result of abundant growth of phytoplankton was reported.

Table 2.1 Variations in Total Number of Species and Total Quantity of Phytoplankton in Different Seasons in River Ganga at Varanasi during 1957-58 (Laxminarayan, 1965)

Seasons		Total number of species with total phytoplankton			
		Diatoms	Blue-Greens	Greens	Euglenineae
Summer	Species	30	13	36	3
	Phytoplankton	888717	105675	55545	2955
Rainy	Species	6	3	4	0
	Phytoplankton	36448	1625	975	0
Winter	Species	12	8	16	1
	Phytoplankton	1764997	158540	32641	2500

Due to environmental and nutritional constraints large-scale algal die-off occur and deposit on the stream bottom and begin to decompose. This decomposition results not only in demands of oxygen from stream resources but also in the release of mineral

nutrients such as nitrates and phosphates upon which additional plant life can feed (Shrihari, 1999).

2.5 Summary

The review of literature presented gives the glimpse of the type of information available on the photosynthesis in aquatic systems and water quality and biology of river Ganga in general. Despite of the most used river of the country and its religious importance, studies carried out in terms of river water quality and ecology are very scanty and scattered. The photosynthetic activity seems to have played an important role in maintaining DO levels in the river Ganga despite of high pollution loads. However, almost no investigations were directed to study the photosynthetic activity and waste assimilative capacity. Observations relating to high DO levels have always been looked upon as experimental error. Investigations are necessary to analyse the trend in water quality parameters from the collected data to suggest changes in the river's physical, chemical and biological characteristics.

3 Objectives and Protocol

River Ganga has been receiving several tonnes of organic, nutrient and other toxic metal and non-metal loads from several point as well as non point sources along its 2,525 km course from Gangotri to Bay of Bengal. Despite this the dissolved oxygen levels in the river have not deteriorated significantly at most of the locations. One of the main reasons for this appears to be contribution due to photosynthetic activity. Attempts have been made in the past to study aquatic life in some stretches of the river Ganga. Similarly some information is available on types of algae and a few aspects of the photosynthetic activity in a few stretches of the river based on the scattered, short-duration studies. Also water quality monitoring programme has been taken up by National River Conservation Directorate (NRCD) with the assistance of several academic and research institutes over the past one and half decade. Prior to this some scattered short-term studies on water quality of the river have been done. However, very little efforts have been done to assess the photosynthetic activity in the river and its impact on the river ecology and water quality in general, and assimilative capacity in particular. As such the major thrust in the present research has been to examine the trend of water quality parameters which are considered to influence the photosynthetic activity and to analyse some aspects of the photosynthetic activity based on the limited water quality survey and some laboratory experiments over a period of one year in the most polluted stretch, namely Kannauj – Kanpur stretch, of river Ganga. Specifically following objectives and protocols were set.

- Analysis of the trend in some water quality parameters of River Ganga from point of view of significance in photosynthetic activity.

- Compare the nutrient levels, which are of significance in photosynthesis process, in some major rivers of world.

- Study of the diurnal variation in some water quality parameters to assess the photosynthetic activity in river Ganga.

- Assessment of oxygenation potential due to photosynthetic activity in the selected stretch.

- Establish the significance of various river water quality parameters for their contribution in the oxygen production due to photosynthetic activity.

- Examine the impact of anaerobically treated combined tannery and domestic effluents from Common Effluent Treatment Plant (CETP) at Jajmau, Kanpur into the river Ganga.

4 Methods

In order to analyse the photosynthesis aspects in the most polluted stretch (from Fatehgarh to down stream of Kanpur in the state of Uttar Pradsh, designated as Kannauj – Kanpur Stretch) of the river Ganga the study was carried out in two parts. The first part of the study involved compilation and analysis of the information on river water quality from studies carried out in the past. The second part of the study aimed at collection of primary data on some aspects related to the photosynthesis in the selected stretch.

4.1 Part I: Compilation and Analysis of the Available Information

This part of the study involved two phases. In the first phase information available regarding the river water quality parameters, which were considered to be significant from the point of view of photosynthesis, was scanned and compiled. The second phase of this part of the study involved statistical analysis of the trend in various river water quality parameters considered significant from the point of view of photosynthetic activity in the river.

4.1.1 Compilation of Available River Water Quality Studies

The studies reported by Saxena (1966), Bhargava (1977), Central Pollution Control Board for the period 1983-1989 (CPCB, 1991) and IIT Kanpur for the period 1997-1999 (Tare, 1997; 1998; 1999) in the Kannauj – Kanpur Stretch of the river Ganga were found to be useful for the present research. Also the studies reported by Laxminarayan for the

period 1957-58 (Laxminarayan, 1965) and Agrawal *et al.* (1976) were used for comparison and drawing some inferences. A brief description of each of these studies is presented in this section for ready reference.

Saxena (1966) carried out river water quality monitoring studies over a period of one year in 1965-66. Samples were collected once in a month from several sampling locations situated between Bhaironghat pumping station in Kanpur, UP and Kishanpur village approximately 6 km down stream of Jajmau, Kanpur, UP. Parameters monitored included temperature, turbidity, total solids, pH, alkalinity, hardness, chloride, DO, BOD, nitrate, phosphate, tannin and coliform count.

Bhargav (1977) conducted river water quality monitoring studies for two seasons (Summer: May/June 1976 and Winter: November/December 1976) starting from Rishikesha, UP to Varanasi, UP. Eight monitoring stations were chosen between Kanpur upstream to Kanpur downstream. The parameters included temperature, conductivity, pH, alkalinity, hardness, chloride, DO, BOD and ammonical nitrogen.

Central Pollution Control Board, New Delhi (CPCB, 1991) and IIT Kanpur (Tare, 1997; 1998; 1999) have reported monthly observations on various river water quality parameters at different sites selected in the Kannauj – Kanpur stretch during 1983-1989 and 1997-1999 respectively. The samples were collected every month between 10^{th} to 15^{th} day of the month at mid stream from 30 cm below the water surface. The parameters included temperature, pH, alkalinity, DO, BOD, ammonical nitrogen and total Kjeldahl

nitrogen. The 1983-1989 period is considered as Pre Ganga Action Plan Phase I (GAP Phase I) Period while 1997-1999 is considered as Post GAP I period.

Laxminarayan (1965) conducted water quality monitoring of river Ganga during 1957-1958 at Varanasi. Samples were collected fortnightly at three arbitrarily selected sites from 45 –60 cm below the water surface. The parameters included alkalinity, chloride, sulphate, sulphide, DO, BOD, ammonical nitrogen, total Kjeldahl nitrogen, nitrite and nitrate.

Agarwal (1976) in order to estimate physicochemical indicators of faecal pollution of Ganga water at bathing ghats and sewage outfalls in Varanasi conducted water quality monitoring during 1972-1973. The parameters monitored included total solids, chloride, DO, BOD, COD, ammonical nitrogen, nitrite and nitrate.

4.1.2 Statistical Analysis of Trends in River Water Quality Parameters

To study the overall trend of water quality in river Ganga at Kanpur down the years, water quality parameters reported by Saxena (1966) and Bhargav (1977) were compared with corresponding water quality parameters obtained from Pre GAP Phase I, Post GAP Phase I and present studies. The parameter values were considered to be significantly different (i.e. increasing or decreasing) if the null hypothesis that the means are equal is rejected at 95 % confidence level. In order to test the null hypothesis that the "k" population means are equal, two estimates of variance (σ^2_m: variation within the samples having k(n-1) degrees of freedom and σ^2_w variation among sample means having k-1

degrees of freedom) were compared. The null hypothesis was rejected if the critical value of F statistics (computed value of $F = F_c = \sigma^2_w/\sigma^2_m$) exceeds tabulated F at 95 % confidence level {F0.05(k-1, nk-k)}.

4.2 Part II: Collection of Primary Data

The principle objective of collecting primary data was to supplement the available data on river water quality in the selected stretch so as to analyse some aspects of the photosynthetic activity in the river. The water quality survey programme was planned to generate data with respect to (i) nutrient levels in the river, (ii) chlorophyll-a levels in the river, (iii) diurnal variations in DO and alkalinity, and (iv) oxygen production rates due to photosynthesis in the river.

4.2.1 Description of the Selected Sites

Six sites were selected in the most polluted stretch of the river Ganga from Fatehgarh to Kanpur in the state of Uttar Pradesh namely, Fatehgarh, Kannauj, Bithoor, Bhaironghat, Shuklaganj and Jajmau. These sites were selected because they were included in the Ganga Water Quality Monitoring Programme conducted by the National River Conservation Directorate (NRCD), Ministry of Environment and Forests (MoEF), Government of India, New Delhi. The main reason for selecting these sites was the availability of a lot of historical and background water quality data.

Fatehgarh is about 140 km upstream of Kanpur. Beside domestic waste, chemical industries and sugar mills in Gajraula, fertilizers and local dye industries are the main

sources of pollution here. At Kannauj, 80 km upstream of Kanpur, highly polluted river Kali meets Ganga. Scent industries are the main source of organic loading here. Bithoor is in the outskirts of Kanpur. Agricultural and surface runoff, and effluents from small-scale industries are major sources of pollution at this site. To meet the domestic water demand of Kanpur city, river water is pumped from a dredged channel at Bhaironghat. From this site onwards many small and large drains meet the dredge channel which at some downstream location meets the main stream of Ganga at Shuklaganj. At Jajmau, sampling was done at the village Jane where effluent from 36 mld common effluent treatment plant treating combine tannery and domestic wastewater and 5 mld treatment plant treating domestic wastewater meet the river. Both these treatment plants are based on Upflow Anaerobic Sludge Blanket (UASB) technology.

4.2.2 River Water Sampling

River water samples were collected at each site during 10^{th} to 15^{th} day of every month over a period of eight months starting from November 1999. All samples were collected from mid stream at 0.5 m below the water surface. For diurnal variations in DO and alkalinity, samples were collected at 4 h interval. Estimation of temperature, pH, DO and alkalinity were done at the site immediately after the collection of the sample. Five liter samples collected from each site were transported and brought to the environmental engineering laboratory for the estimation of other parameters such as turbidity, BOD, ammonical nitrogen, total Kjeldahl nitrogen, nitrite nitrogen, nitrate nitrogen, total and reactive phosphorous and chlorophyll-a. During the transport samples were kept in icebox and subsequently transferred to the refrigerator. Samples were analysed for various parameters as soon as possible as described in Section 4.2.4.

4.2.3 Estimation of Oxygen Production Rates due to Photosynthesis

Oxygen production rate due to photosynthesis was estimated at selected sites by conducting DO estimation on samples kept in light and dark for a fixed period. Four BOD bottles were filled with samples collected from each site at mid night and were properly wrapped with carbon paper. Two of these bottles were kept in the dark. The remaining two bottles, after removing the carbon paper, were exposed to day light for 6 h. The increase in the DO levels in the bottles exposed to the light and the DO depleted in the bottles kept in dark were used appropriately in calculating the oxygen production rates due to photosynthesis and were expressed as mg/L O_2 produced per h.

4.2.4 Analytical Techniques

Most of the analytical techniques followed were of routine type and were conducted as per the Standard Methods for the Examination of Water and Wastewater (APHA, *et al.*, 1995). A listing of such techniques along with instruments used, name of the method, reference, etc. are presented in Table 4.1. Technique for chlorophyll-a estimation as adopted in this study is given as follows.

Chlorophyll-a was estimated in river water sample by extraction with acetone extractant (90 % acetone and 10 % magnesium carbonate solution). One liter sample was filtered through a filter paper (Whatman GF/C: 0.45 μm pore size; 4.7 cm diameter glass microfibre filter) using vacuum filtration assembly. The time for extracting chlorophyll-a was estimated by macerating residue for 5, 10, 12 and 15 minutes respectively under

identical conditions in acetone extractant. Based on the observations (refer Figure 4.1), a duration of 12 minutes was chosen as the macerating time. Filter paper with residues were crushed in pestle and mortar for 12 minutes and carefully transferred to centrifuge tubes with repeated washing by acetone extractant. Centrifugation was done for 10 minutes at 5000 rpm (> 500g). Optical Density (OD) of the supernatant was measured at 664 and 750 nm using 1 cm cell. The extract was acidified with 2 drops of 0.1N HCl and gently agitated. OD was measured between 1-2 minutes after acidification at 665 and 750 nm using 1 cm cell. 90 % aqueous acetone solution was used as blank. Chlorophyll-a in μg/L was estimated as $\{26.7\ (OD664_b - OD665_a)\ A\}/B$. Here, A and B are the total volume in liters of the extractant and filtered sample respectively, and $OD664_b$ and $OD665_a$ are the turbidity corrected OD values before and after acidification using 1 cm cell respectively. The turbidity corrected OD values were obtained by subtracting the OD values at 750 nm from the OD values at 664 and 665 nm respectively.

Table 4.1 Analytical Methods Employed During Experimentation

Test Parameter	Method Used	Instrument Used	Reference
DO	Winkler's Method with Azide Modification		APHA, *et al.* (1995)
BOD	-do-		-do-
pH	Glass Calomel Electrode	Digital pH meter	
Phosphate	Colorimetry, Stannous Chloride	1cm cell, 690nm Spectrophotometer	Standard Methods APHA, *et al.* (1995)
Ammonia Nitrogen	Colorimetry, Nesslerisation	1cm cell, 425nm Spectrophotometer	-do-
TKN	Extraction in 3N H_2SO_4 & Nesslerisation	-do-	Thompson and Morrison (1951)
Turbidity		Turbiditymeter/Systronics	
Nitrite	Colorimetry, NED dihydrochloride method	1cm cell, 543nm Spectrophotometer	APHA, *et al.* (1995)
Nitrate	Colorimetry, Chromotropic acid method	1 cm cell, 410nm Spectrophotometer	Standard Methods APHA, *et al.* (1985)
Chlorophyil-a		Extraction in 90%aq acetone	Standard Methods APHA, *et al.* (1995)

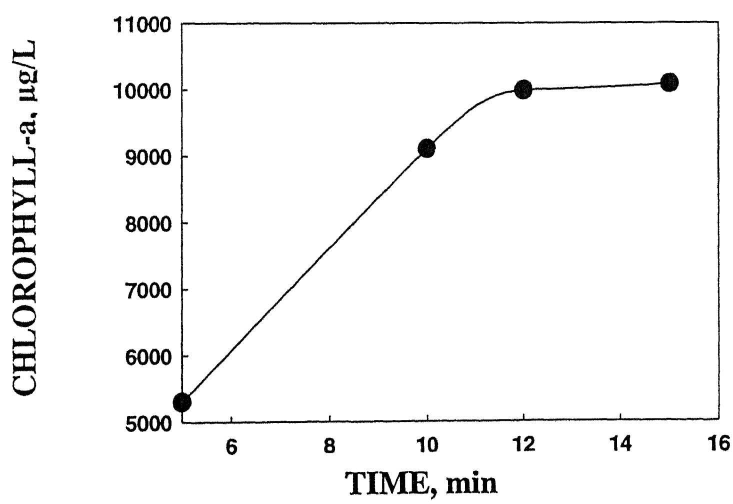


Figure 4.1 Estimation of Time for Chlorophyll-a Extraction

5.4 General

The thrust of the present research has been on investigating some aspects of photosynthetic activity in the river. This is to facilitate a fair assessment of the oxygenation potential, and hence waste assimilative capacity, in order to plan and implement future intervention schemes under Ganga Action Plan (GAP) in more effective manner. The study was carried out in two parts. In the first part emphasis was laid on analysis of the available river water quality data as obtained from different studies carried out by various researchers and agencies over the 3-4 decades from the point of view of photosynthetic activity. The second part of the study aimed at collecting some primary data in order to further substantiate the role of photosynthesis activity, and get some preliminary qualitative and quantitative information on the most polluted stretch of the river Ganga namely, Kannauj – Kanpur stretch in the state of Uttar Pradesh, starting from Fatehgarh to down stream of Kanpur. Most of the results are presented graphically and inferences are made using statistical analysis.

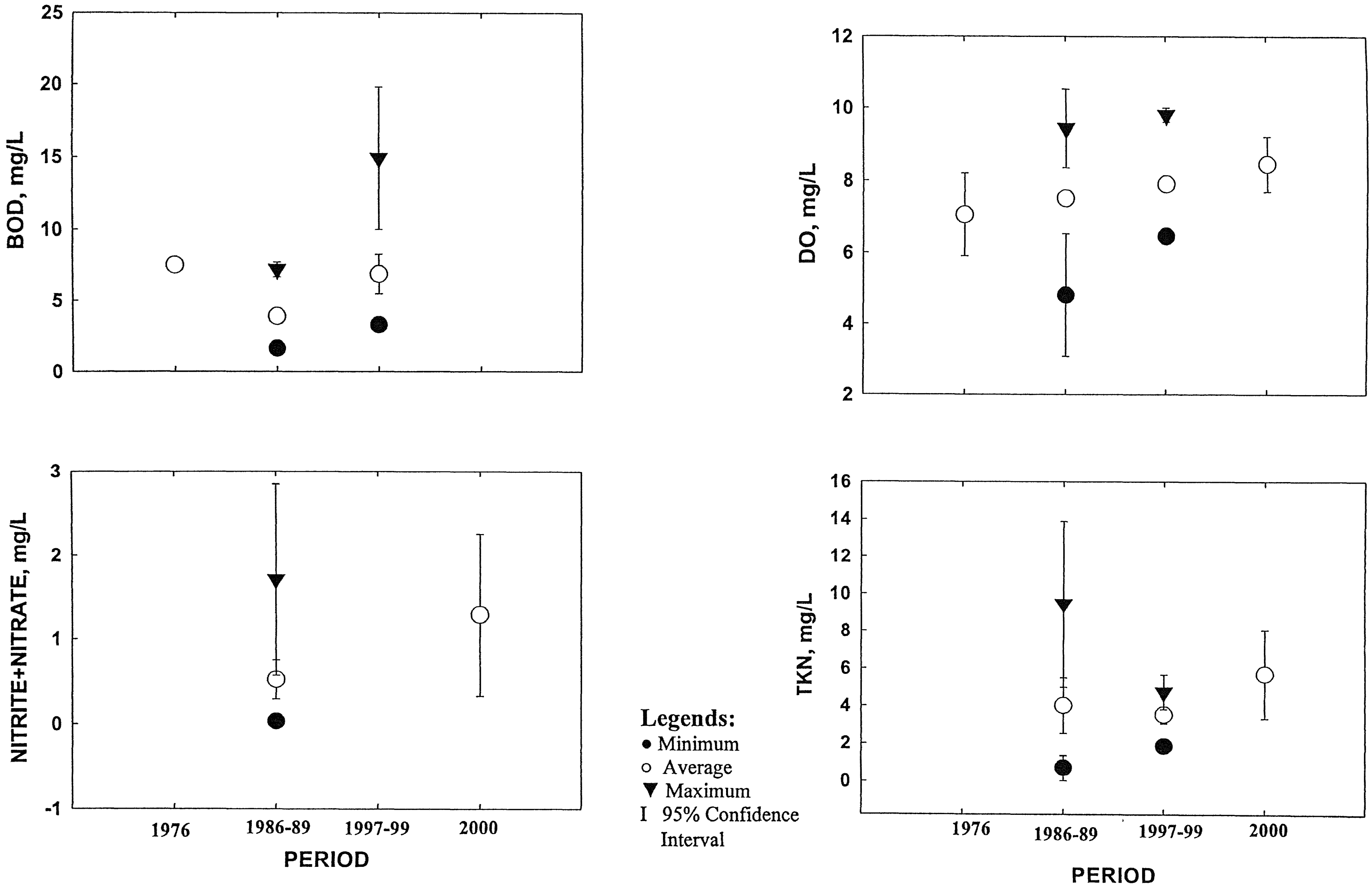
5.4 Analysis of the Trends in Water Quality Parameters in River Ganga

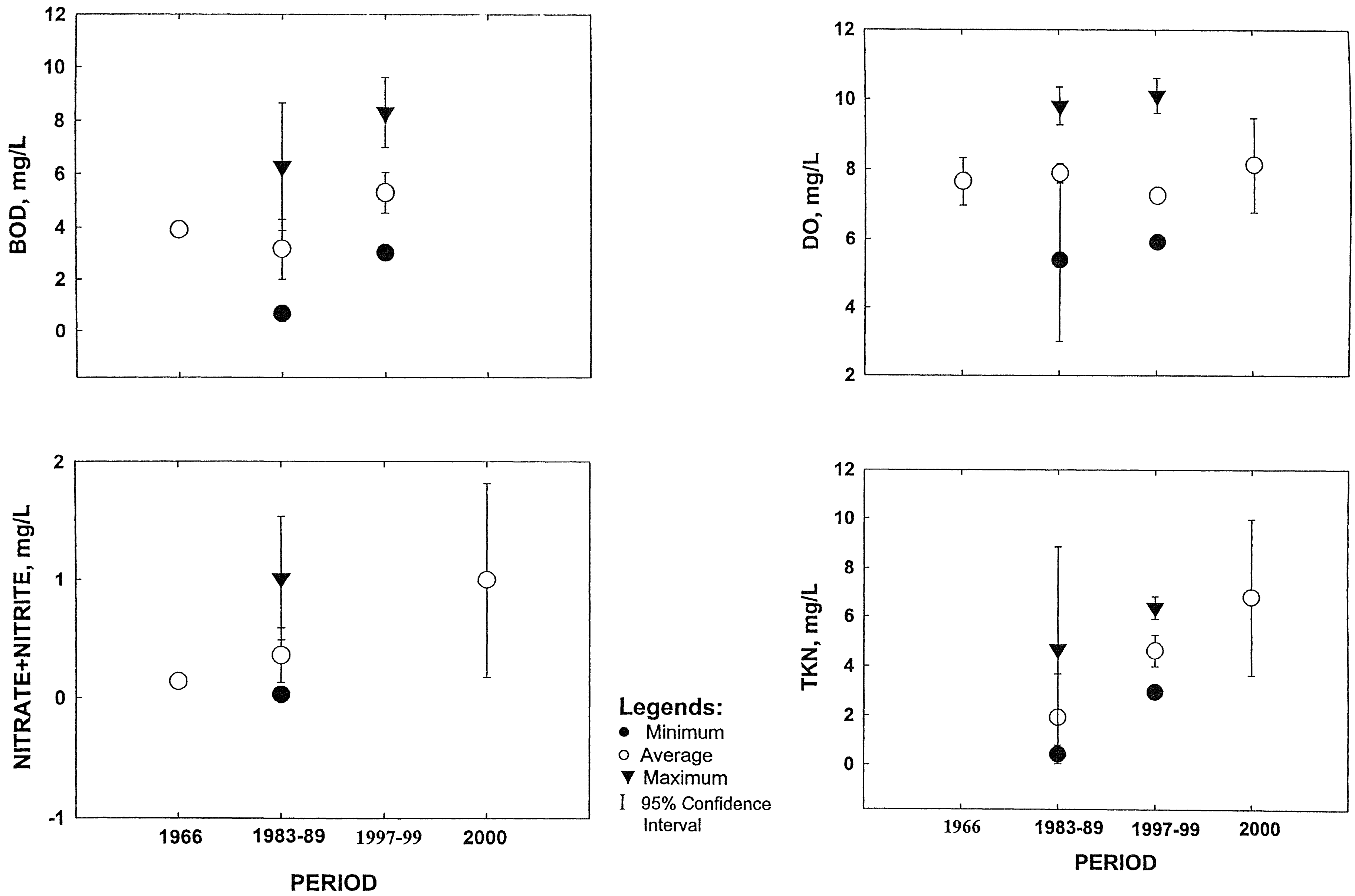
One of the important attributes of the photosynthetic activity is the oxygen production, and hence if there is substantial photosynthetic activity in the river than it should have an impact on DO and BOD levels in the rivers. Further the nutrients such

as nitrogen and phosphorous should be present. As such attempt has been made to analyse the trends in these parameters at three different sites in the Kannauj – Kanpur stretch. The results are presented in Figures 5.1 to 5.3. For this analysis the data are taken from Saxena (1966), Bhargav (1977), CPCB (1990) for the period 1983 – 1989 (Pre GAP Phase I), Tare (1997, 1998; 1999) for the period 1997 – 1999 (Post GAP Phase I), and present studies. Analysis for the phosphorous levels could not be made due to lack of data. The statistical comparison of the Pre GAP Phase I and Post GAP Phase I results reveals the following.

- The minimum BOD levels at all the three sites have increased. The average and maximum BOD levels have remained unchanged at Kannauj, increased at Shuklaganj and decreased at Jajmau. (Refer Table 5.1).
- At Kannauj, maximum DO levels have remained unchanged while the minimum and average DO levels have increased. At Shuklaganj, maximum and minimum DO levels have remained unchanged while the average DO levels have slightly decreased. At Jajmau, however, both minimum and average DO levels have gone down despite the decrease in BOD levels and maximum DO levels have increased. (Refer Table 5.2).

The aforementioned results suggest that, in general DO levels have not gone down significantly despite the fact that waste loading on the river has been on the rise. Also, at Jajmau where the BOD levels have reduced, the DO levels have also gone down Thus, in general the increased BOD loading has not affected the DO levels significantly. Also the DO levels much higher than the saturated DO values have been observed many times (Figures 5.1-5.3). This suggests oxygen production due to photosynthesis in the river.


BOD, mg/L
DO, mg/L
NITRITE+NITRATE, mg/L
TKN, mg/L
1976
1986-89
1997-99
2000
PERIOD
Legends:
● Minimum
○ Average
▼ Maximum
I 95% Confidence Interval


BOD, mg/L
DO, mg/L
NITRATE+NITRITE, mg/L
TKN, mg/L
1966
1983-89
1997-99
2000
PERIOD
Legends:
Minimum
Average
Maximum
95% Confidence Interval

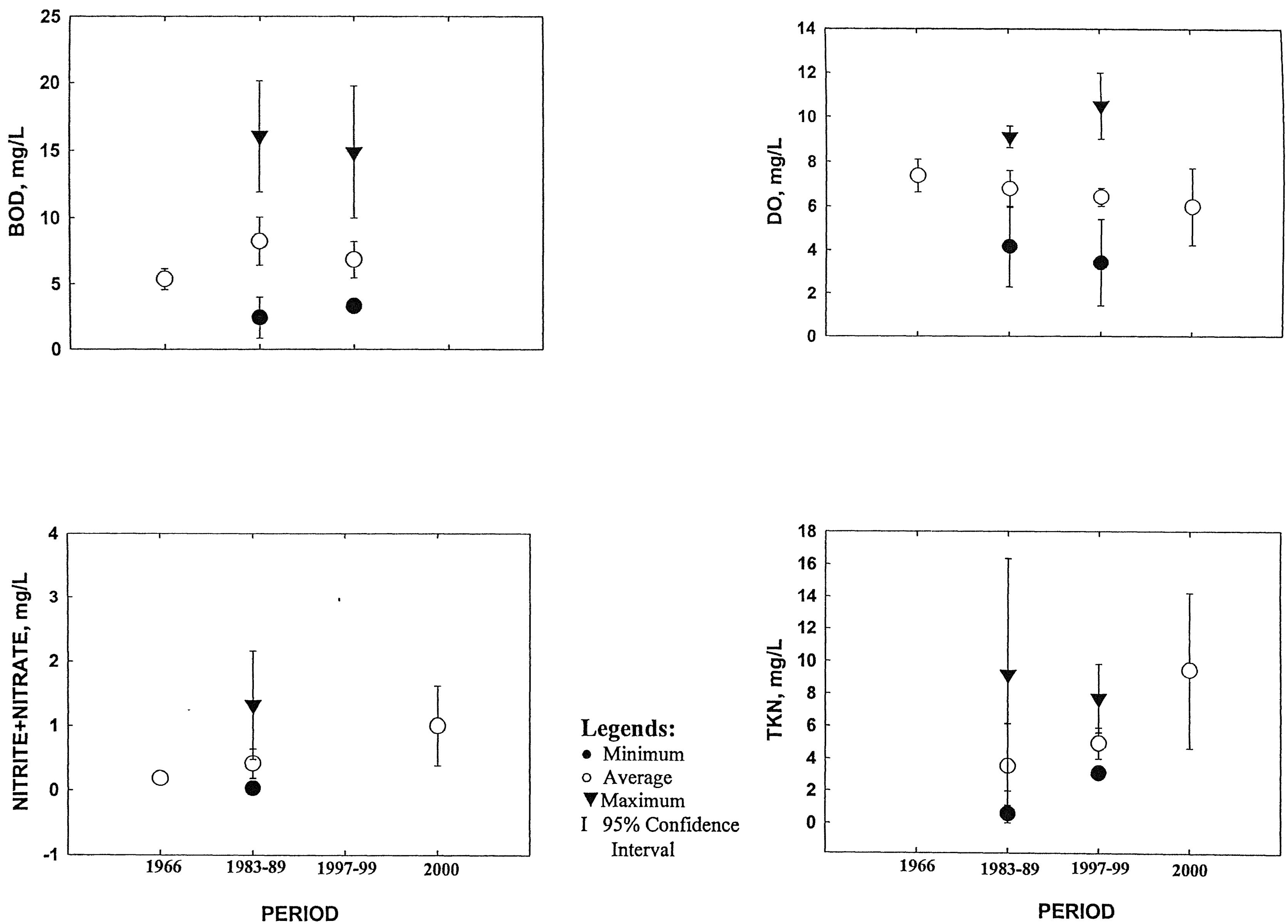

BOD, mg/L
DO, mg/L
NITRITE+NITRATE, mg/L
TKN, mg/L
1966
1983-89
1997-99
2000
PERIOD
Legends:
● Minimum
○ Average
▼ Maximum
I 95% Confidence Interval

Table 5.1 Significance of BOD at Various Sites

Site		1983-89			1997-99			Computed F	Critical F at 95% Confidence Level	H_0	Trend of Parameter Values
		μ	σ	n	μ	σ	n				
Kannauj	Maximum	7.18	0.52	39	6.8	2.5	36	0.86	4.0	Accepted	Unchanged
	Minimum	1.63	0.28	39	2.3	0.1	36	184.6	4.0	Rejected	Increasing
	Average	3.9	0.48	39	3.76	0.61	36	1.24	4.0	Accepted	Unchanged
Shuklaganj	Maximum	6.26	2.39	80	7.23	1.8	36	5.49	3.92	Rejected	Increasing
	Minimum	0.67	0.31	80	3.2	0.1	36	2660.4	3.92	Rejected	Increasing
	Average	3.15	1.15	80	4.97	0.72	36	84.26	3.92	Rejected	Increasing
Jajmau	Maximum	16.06	4.1	84	12.1	5.5	36	22.56	3.92	Rejected	Decreasing
	Minimum	2.42	1.54	84	3.46	0.4	36	18.7	3.92	Rejected	Increasing
	Average	8.25	1.8	84	6.35	1.33	36	38.6	3.92	Rejected	Decreasing

H_0 : Hypothesis that the parameter values are essentially same
μ Average.
σ Standard deviation.
n Number of observations

Table 5.2 Significance of DO at Various Sites

Site		1983-89			1997-99			Computed F	Critical F at 95% Confidence Level	H_0	Trend of Parameter Values
		μ	σ	n	μ	σ	n				
Kannauj	Maximum	9.41	1.09	41	9.63	0.28	36	1.38	4.0	Accepted	Unchanged
	Minimum	4.8	1.72	41	6.2	0.4	36	22.8	4.0	Rejected	Increasing
	Average	7.5	0.13	41	7.73	0.24	36	28.36	4.0	Rejected	Increasing
Shuklaganj	Maximum	9.88	0.54	84	9.8	0.58	36	0.636	3.92	Accepted	Unchanged
	Minimum	5.37	2.38	84	5.66	0.18	36	0.632	3.92	Accepted	Unchanged
	Average	7.88	0.27	84	7.12	0.17	36	304	3.92	Rejected	Decreasing
Jajmau	Maximum	9.1	0.49	84	10.1	1.34	36	43.4	3.92	Rejected	Increasing
	Minimum	4.15	1.84	84	3.1	1.67	36	10.23	3.92	Rejected	Decreasing
	Average	6.77	0.83	84	6.4	0.32	36	1270.6	3.92	Rejected	Decreasing

H_0 : Hypothesis that the parameter values are essentially same
μ Average
σ Standard deviation
n Number of samples

Figures 5.1 to 5.3 also show that nitrogen levels in the river in this stretch are high. Also in general the nitrogen levels have changed significantly. The statistical comparison of the total Kjeldahl nitrogen (TKN) levels between pre GAP Phase I and post GAP Phase I period at the three sites reveals the following.

- The maximum and average values of TKN at Kannauj have decreased while the minimum TKN levels have increased. (Refer Table 5.3).
- The minimum, maximum and average TKN levels have increased at Shuklaganj where about 100 mld of untreated wastewater continues to be discharged into the river. (Refer Table 5.3).
- The minimum and average values of TKN have increased at Jajmau. However, the maximum values of TKN have decreased at the same site. (Refer Table 5.3).
- The nitrite and nitrate levels appear to show increasing trend at all the three sites.

The aforementioned results suggest that nitrogen levels are rising in the downstream of Kanpur. Also the nitrite and nitrate levels are increasing which may be an indication of increased nitrification in the rivers. Further the nitrogen levels are sufficiently high to sustain photosynthetic activity in the river.

Figure 5.4 shows that trend of BOD, DO, nitrite and nitrate, and TKN at Varanasi is similar to that in Kanpur. There also the DO levels are maintained reasonably high despite the fact that BOD loading on the river is on the rise. This observation together with observed nitrogen levels suggest possibility of sustaining photosynthetic activity in the river.

Table 5.3 Significance of TKN at Various Sites

Site		1983-89			1997-99			Computed F	Critical F at 95% Confidence Level	H_0	Trend of Parameter Values
		μ	σ	n	μ	σ	n				
Kannauj	Maximum	9.43	4.45	37	4.42	0.87	36	43.9	4.0	Rejected	Decreasing
	Minimum	0.68	0.67	37	1.93	0.24	36	109.4	4.0	Rejected	Increasing
	Average	4.0	1.47	37	3.28	0.47	36	7.79	4.0	Rejected	Decreasing
Shuklaganj	Maximum	4.68	4.1	81	6.1	0.51	36	4.82	3.92	Rejected	Increasing
	Minimum	0.43	0.38	81	2.85	0.17	36	1574.9	3.92	Rejected	Increasing
	Average	1.97	1.77	81	4.43	0.58	36	77.6	3.92	Rejected	Increasing
Jajmau	Maximum	9.16	7.1	84	6.56	2.3	36	5.36	3.92	Rejected	Decreasing
	Minimum	0.57	0.53	84	3.07	0.1	36	903.4	3.92	Rejected	Increasing
	Average	3.54	2.58	84	4.49	1.0	36	5.48	3.92	Rejected	Increasing

H_0 : Hypothesis that the parameter values are essentially same
μ Average
σ Standard deviation
n Number of samples

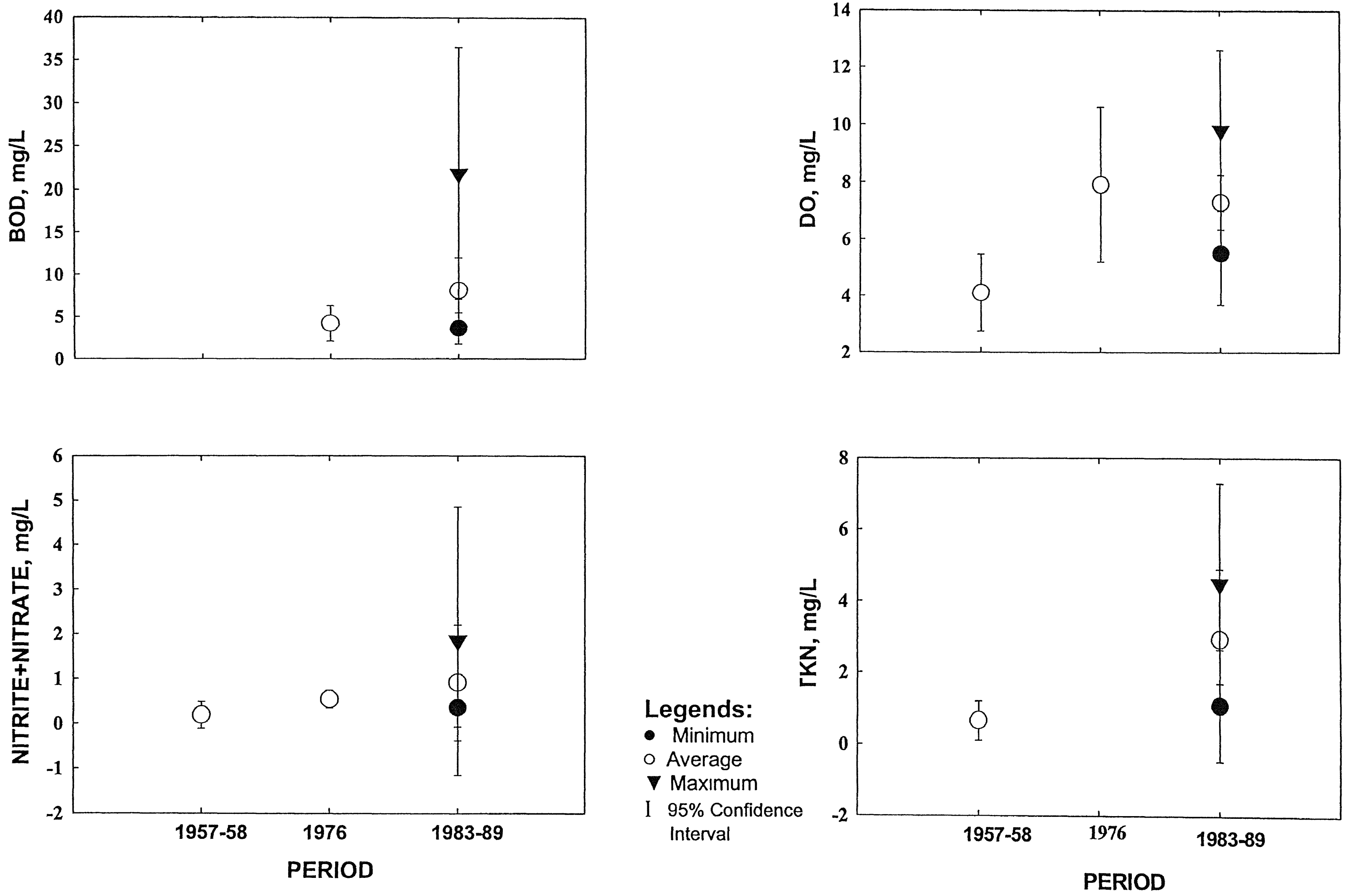


Figure 5.4 Trend of Various Water Quality Parameters at Varanasi, UP

5.3 Comparison of the Nutrient Levels in River Ganga with Some Major Rivers of the World

The nutrient levels play an important role in photosynthesis and eutrophication of aquatic systems. Table 5.4 presents a comparison of the nitrogen and phosphorous levels in four major rivers of the world. As can be seen, nitrogen levels in all the rivers have increased. In a span of 38 years, the nitrogen levels have gone up by approximately 200 % in Nile, 100 % in Mississippi and 112.5 % in Thames. As compared to these rivers, increase in nitrogen level in river Ganga is quite low (65.7 %). However, no information could be obtained for the trend in phosphorous levels. In general nitrogen levels in the rivers Ganga and Thames, which are considered to be more polluted, is higher than that in the rivers Nile and Mississippi. The phosphorous levels in river Ganga also appear to be very high compared to the rivers Nile and Mississippi. As such the level of photosynthetic activity, considering the nutrient levels, tropical climatic conditions and available incident solar radiations, is expected to be significant in river Ganga.

5.4 Assessment of Photosynthetic Activity

In order to substantiate the hypothesis that significant level of photosynthetic activity occurs in the river and to assess some aspects related to photosynthesis, studies were carried out over a period of one year starting from July 1999 till June 2000 in the Kannauj – Kanpur stretch at six selected sites. Emphasis was laid on (i) examining diurnal variation in DO and alkalinity, (ii) oxygen production potential due to photosynthesis and its dependence on various water quality parameters, and (iii) chlorophyll-a levels in the river and their dependence on water quality.

Table 5.4 Nitrogen and Phosphate Concentrations of Some Major Rivers of the World

Name of river	Laxminarayan, 1957		Global Environmental Monitoring System(GEMS), 1995	
	Nitrogen (mg/L)	Phosphate (mg/L)	Nitrogen (mg/L)	Phosphate (mg/L)
Nile	Traces to 0.098	Trace to 0.023	Traces to 0.30	-
Mississippi	0.05 to 0.91	Trace to 0.065	1.1 to 1.79	-
Thames	3.5	-	0.25 to 7.44	-
River Ganga	0.11 to 1.86	0.06 to 2.02	0.21 to 3.083	-

5.4.1 Diurnal Variation in DO and Alkalinity

Figures 5.5 to 5.7 show the diurnal variation in DO levels in the river water at six selected sites in different months. In general DO levels were maximum at 16:00 h and minimum at 4:00 h. The DO levels were on the lower side in the summer or pre mansoon period. Also the lowest values of minimum DO were at Jajmau. The hourly variation in DO values, at all sites throughout the monitoring period of one year, substantiate significant level of photosynthetic activity in the river. Diurnal variation in alkalinity (Figure 5.8 to 5.10), though marginal, also confirms photosynthesis activity in the river in the entire stretch under consideration.

5.4.2 Effect of Various River Water Quality Parameters on Oxygen Production Rates due to Photosynthesis

The oxygen production rates due to photosynthesis were estimated using the principle of light and dark reactions on samples collected at mid night from various sites. The effect of various river water quality parameters on oxygen production rates due to photosynthesis is presented in Figures 5.11 and 5.12. A parameter is considered to have influence on the oxygen production rates and hence photosynthetic activity if the correlation is estimated to be significant at 95 % confidence level. A summary of the statistical analysis presented in Table 5.5 reveals that phosphorous and chlorophyll-a concentrations control the oxygen production rates due to photosynthesis.

5.4.3 Effect of Various River Water Quality Parameters on Chlorophyll-a Content

Figures 5.13 and 5.14 present the effect of various river water quality parameters on the chlorophyll-a levels in the river. The statistical analysis presented in Table 5.6

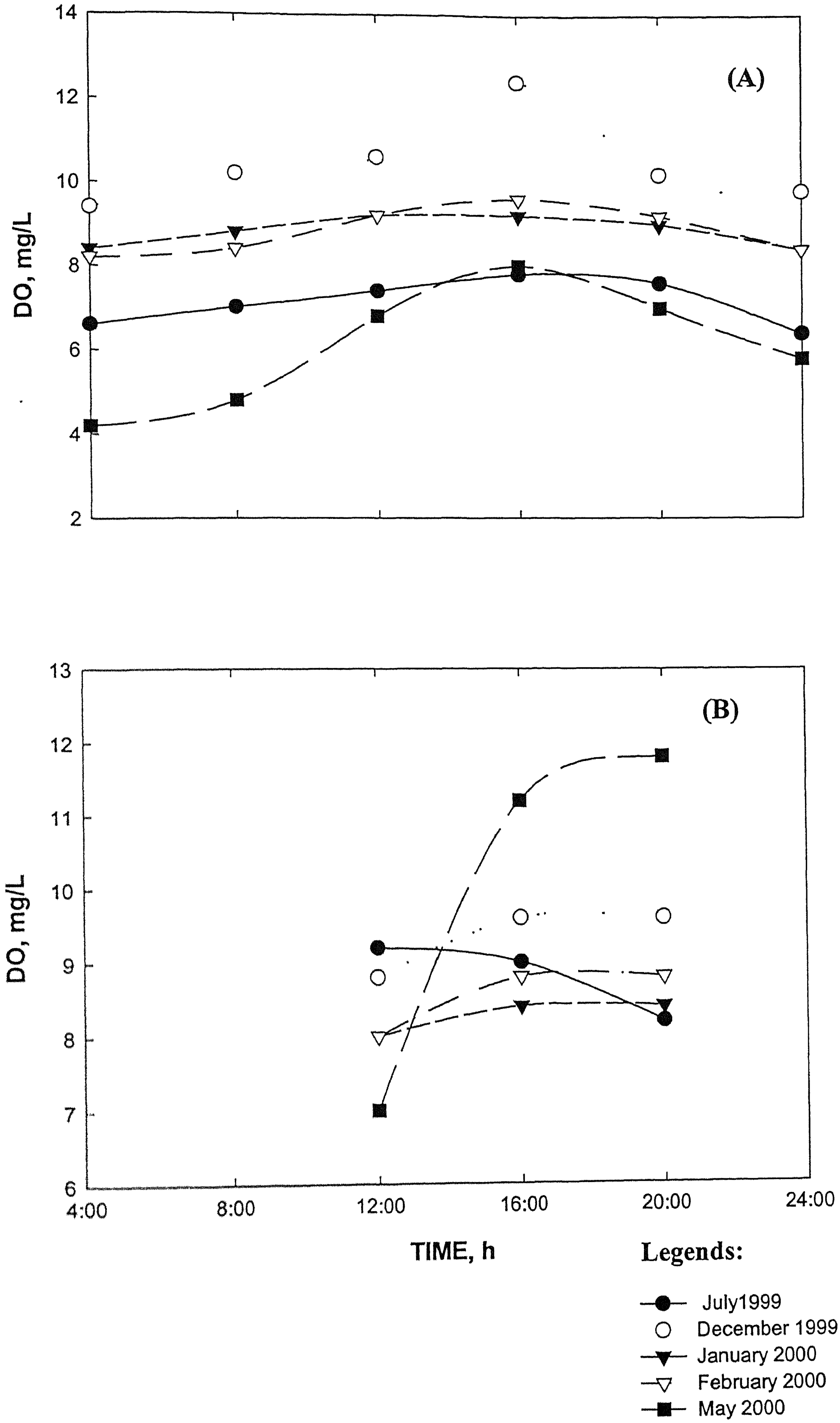


Figure 5.5 Diurnal Variation of Dissolved Oxygen Concentration at (A) Fatehgarh and (B) Kannauj, UP (1999-2000)

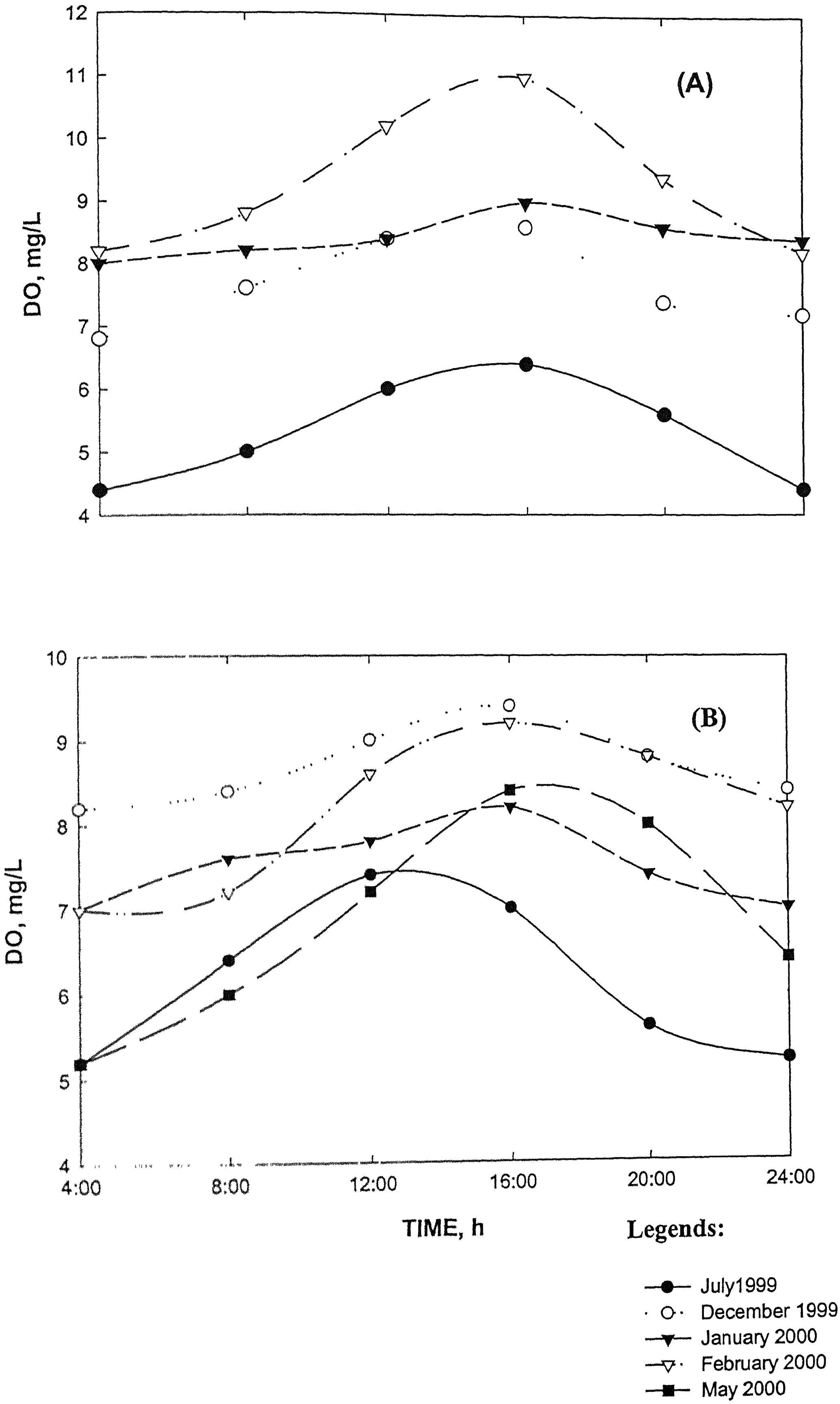


Figure 5.6 Diurnal Variation of Dissolved Oxygen Concentration at (A) Bhaironghat and (B) Bithoor, Kanpur(1999-2000)

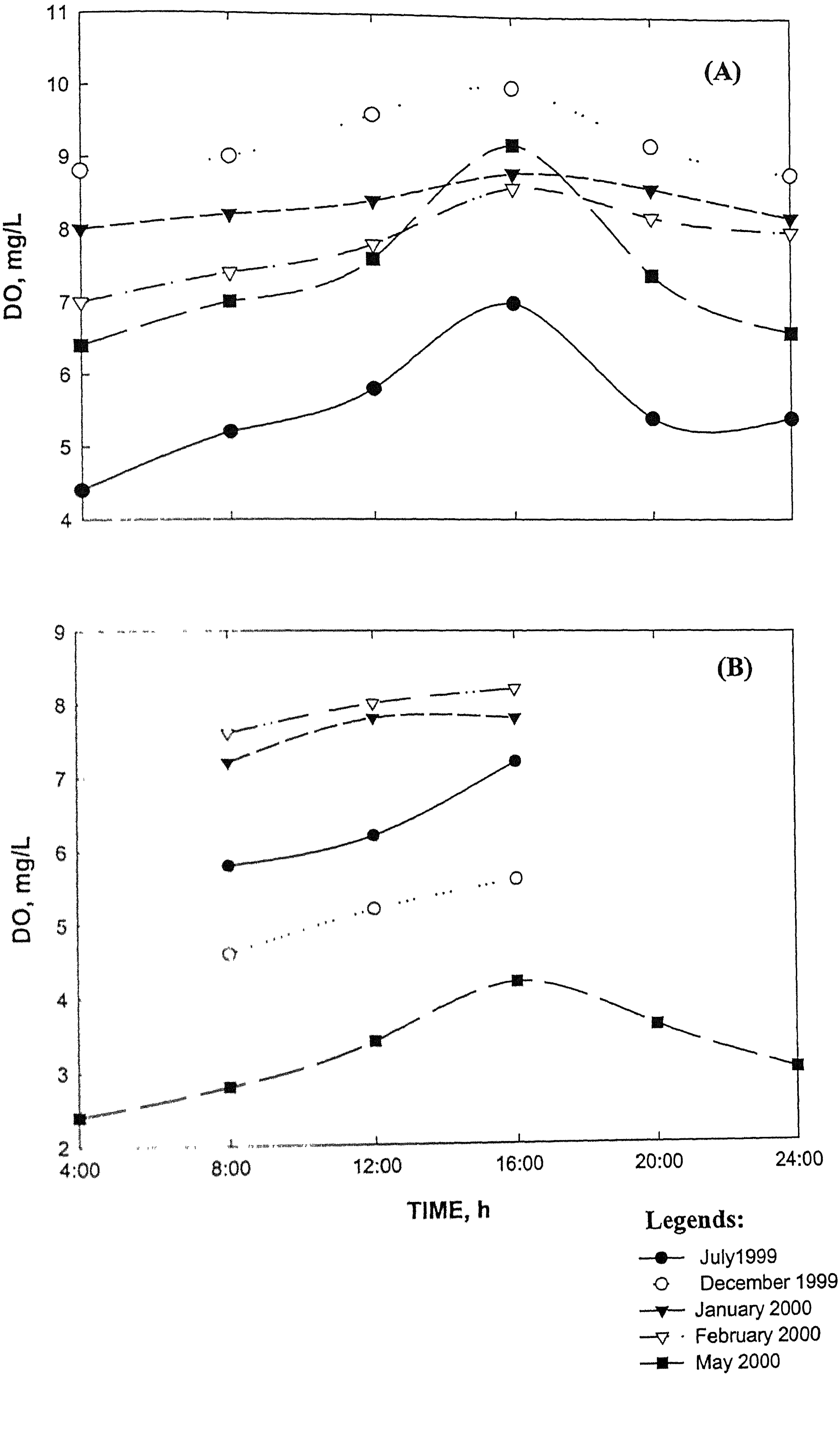


Figure 5.7 Diurnal Variation of Dissolved Oxygen Concentration at (A) Shuklaganj and (B) Jajmau, Kanpur(1999-2000)

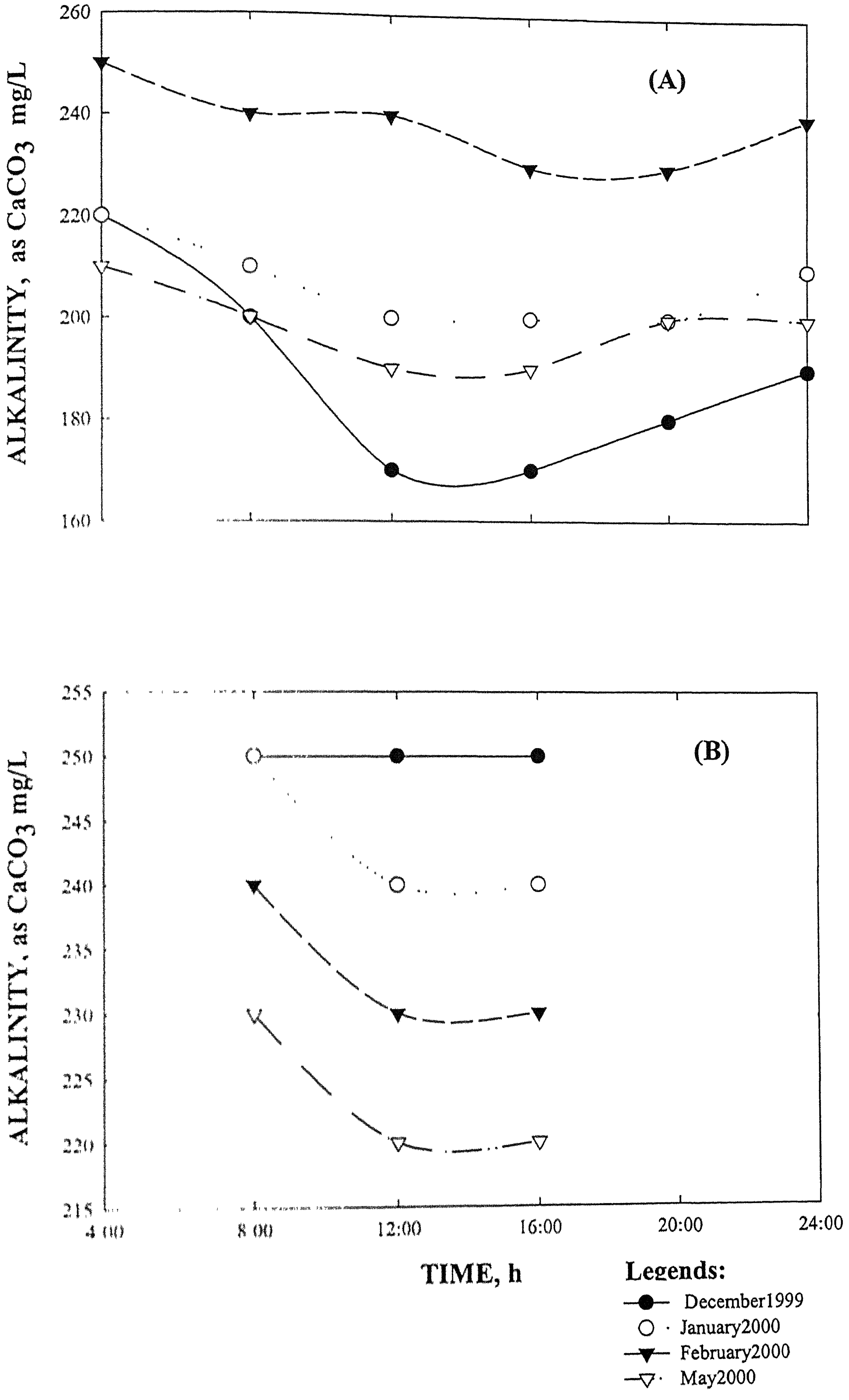


Figure 5.8 Diurnal Variation of Alkalinity at (A) Fatehgarh and (B) Kannauj, UP (1999-2000)

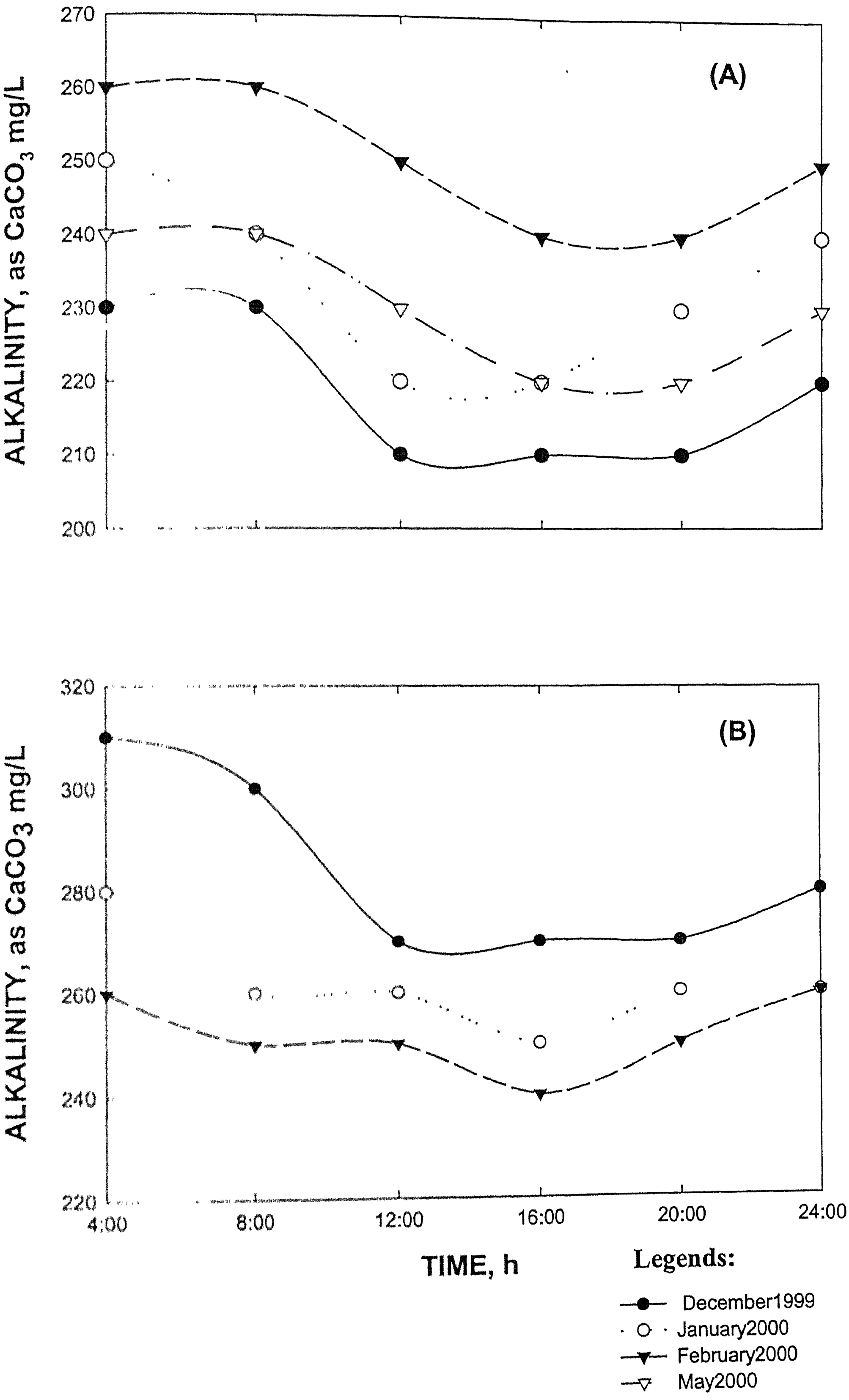


Figure 5.9 Diurnal Variation of Alkalinity at (A) Bithoor and (B) Bhaironghat, Kanpur(1999-2000)

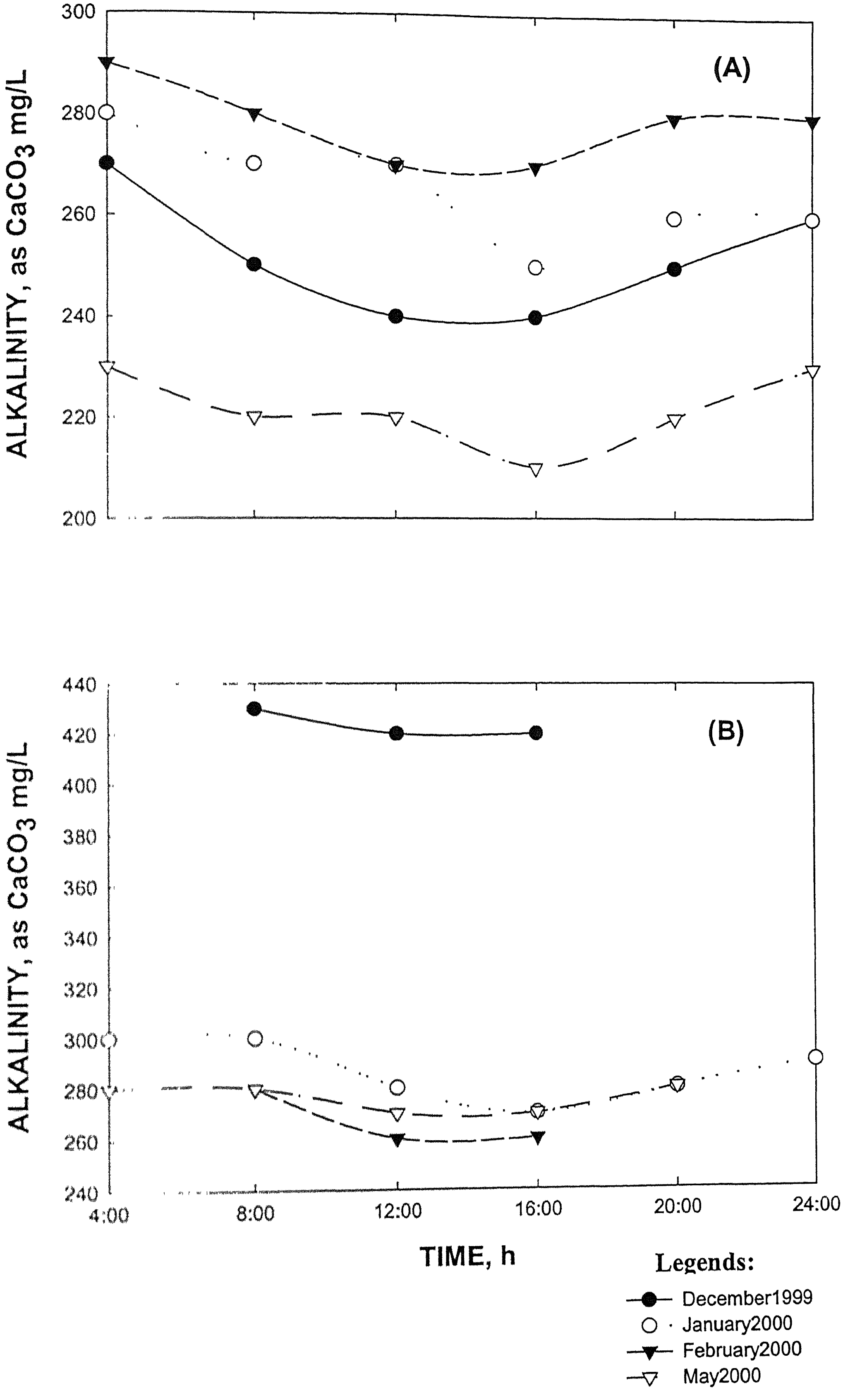


Figure 5.10 Diurnal Variation of Alkalinity at (A) Shuklaganj and (B) Jajmau, Kanpur (1999-2000)

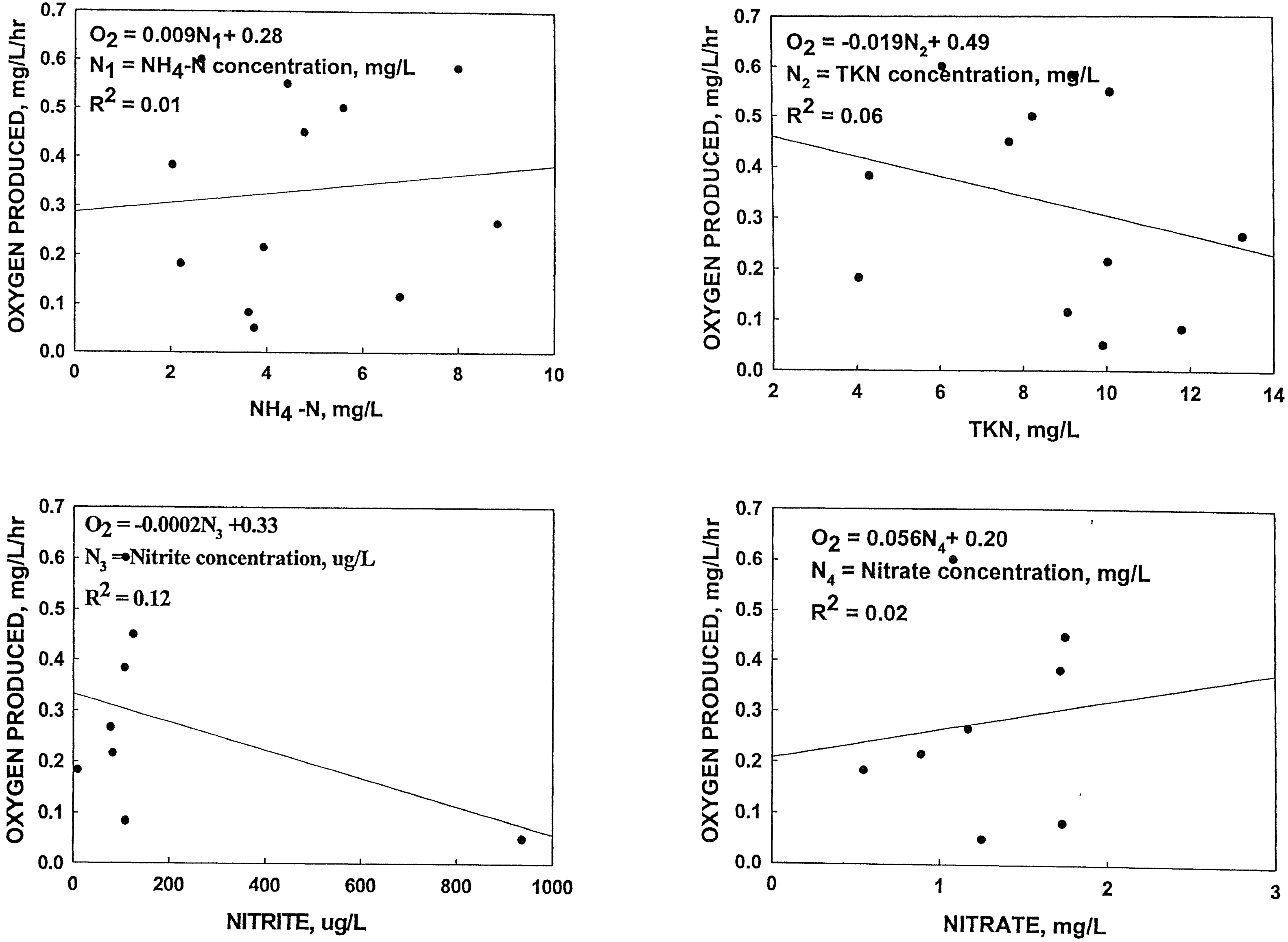


Figure 5.11 Effect of Nitrogen Levels in River Water on Oxygen Produced due to Photosynthesis

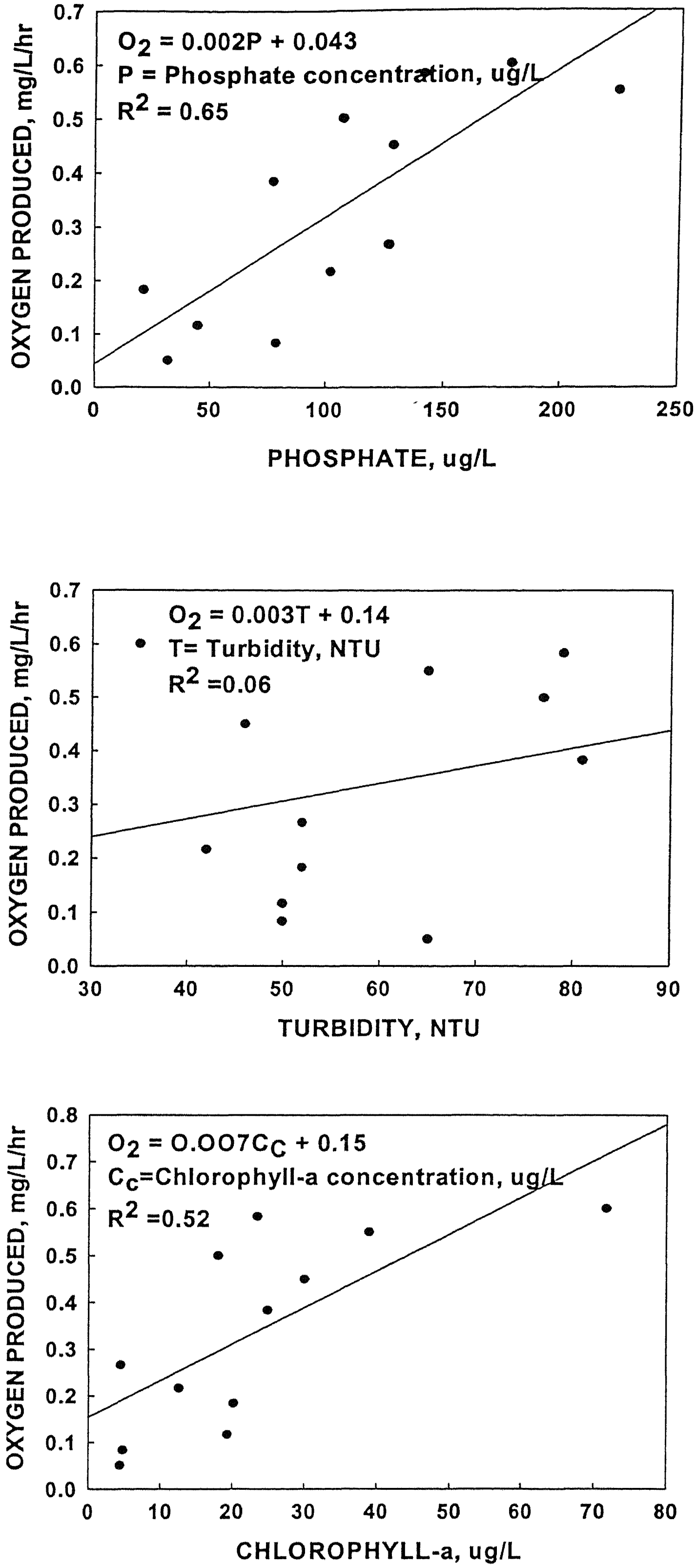


Figure 5.12 Effect of Phosphate, Turbidity and Chlorophyll-a in River Water on Oxygen Produced due to Photosynthesis

Table 5.5 Effect of Various Parameters on Oxygen Produced

Parameter	Correlation Coefficient(R)	Degrees of Freedom	Computed t	Critical t at 95% Confidence Level	H_0	Remark
$NH_4 - N$	0.1	10	0.318	1.812	Accepted	No Effect
TKN	0.25	10	0.814	1.812	Accepted	No Effect
Nitrite	0.35	6	1.179	1.943	Accepted	No Effect
Nitrate	0.14	6	0.45	1.943	Accepted	No Effect
Phosphate	0.806	10	4.3	1.812	Rejected	Positive
Turbidity	0.25	10	0.815	1.812	Accepted	No Effect
Chlorophyll-a	0.72	10	3.28	1.812	Rejected	Positive

H_0: Hypothesis that the slope of line is zero.

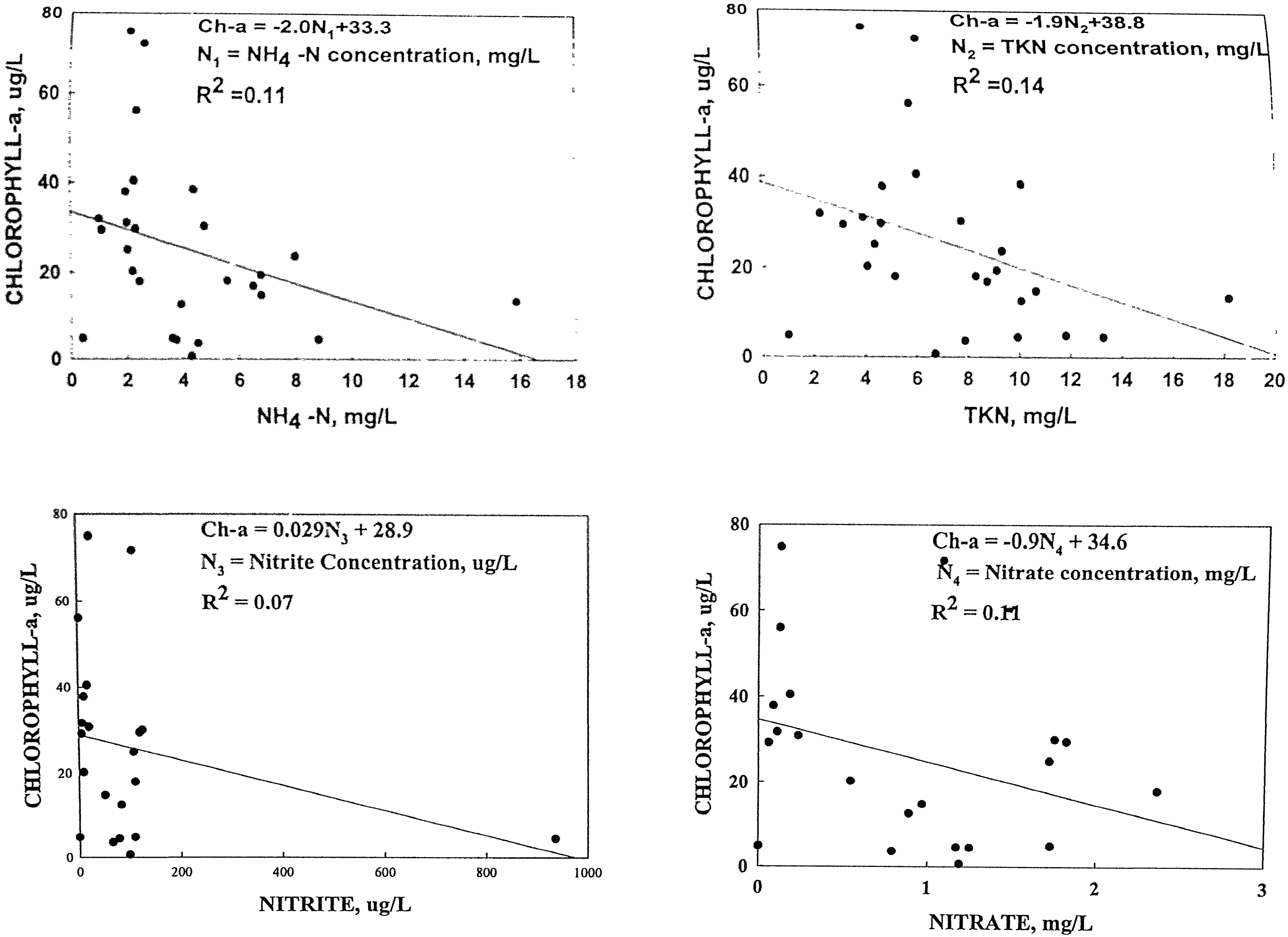


Figure 5.13 Effect of Nitrogen Levels in River Water on Chlorophyll-a Content of River

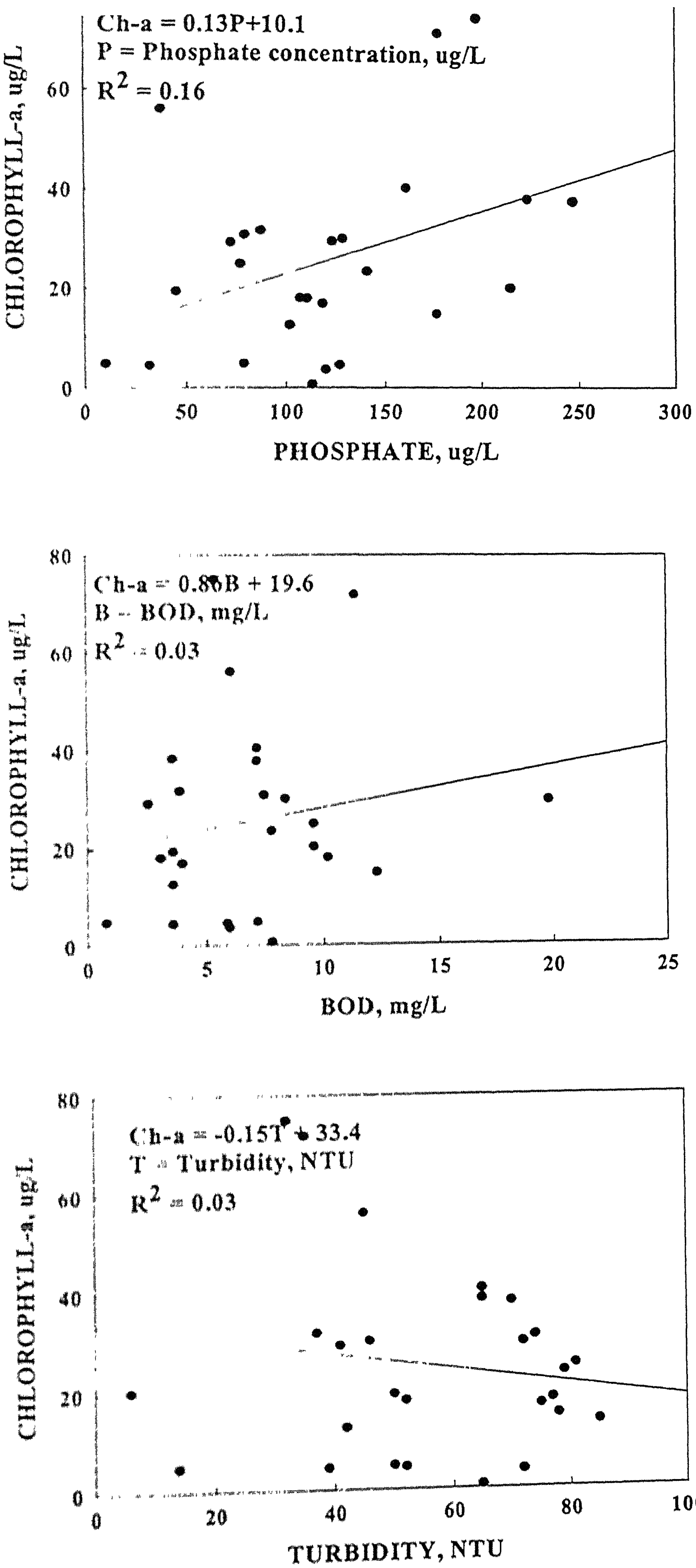


Figure 5.14 Effect of Phosphate, BOD and Turbidity in River Water on Chlorophyll-a Content of River

Table 5.6 Effect of Various Parameters on Chlorophyll-a Content of River Water

Parameter	Correlation Coefficient (R)	Degrees of freedom	Computed t	Critical t at 95% Confidence Level	H_0	Remark
[illegible]	[illegible]	[illegible]	1.76	1.71	Rejected	Negative
TKN	[illegible]	25	1.99	1.71	Rejected	Negative
Nitrite	0.26	19	1.19	1.73	Accepted	No Correlation
Nitrate	0.33	19	1.52	1.73	Accepted	No Correlation
Phosphate	0.40	24	2.13	1.71	Rejected	Positive
BOD	0.17	25	0.88	1.71	Accepted	No Correlation
Turbidity	0.17	25	0.88	1.71	Accepted	No Correlation

H_0: Hypothesis that the slope of line is zero.

suggests that chlorophyll-a content and hence photosynthetic activity is limited by the phosphorous concentration in the river water.

5.4.4 Variation of Phosphate and Chlorophyll-a Levels in the Kannauj – Kanpur Stretch

Since phosphorous and chlorophyll-a concentrations in the river determine the level of photosynthetic activity in the river (refer Sections 5.4.2 and 5.4.3), their variation in the selected stretch is presented for various months in Figure 5.15. Results indicate that phosphorous concentration is higher in the downstream of Kanpur. However, the variation over various months is marginal. The chlorophyll-a levels while do not show significant variation over the entire stretch, appear to vary seasonally.

5.4.5 Sediment Settling Rate in River Ganga

The decay rate of coliforms in the river Ganga is reported to be high compared to the other rivers (Kashiprasad, 1977). It is believed that the water quality and sediments of river Ganga possess special characteristics. However, this has not been substantiated by any scientific studies. One of the special characteristics of sediments is that some fraction is very fine and gets transported over a long distance. To check this a settling analysis test on river water was carried out. The results are presented in Figure 5.16. The results do indicate that the river water carries very fine suspended solids which might get transported over long distance.

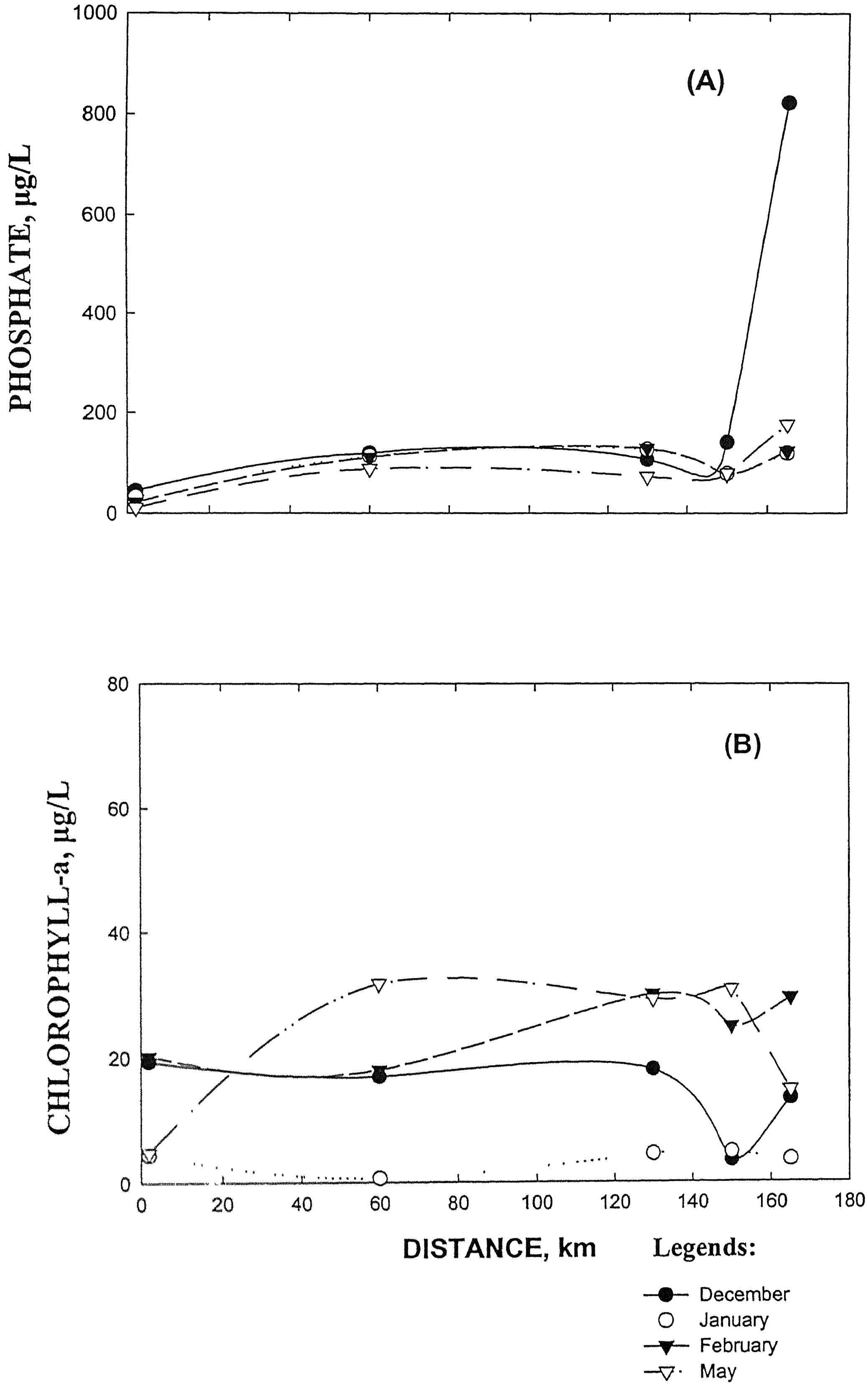


Figure 5.15 Variation of (A) Phosphate and (B) Chlorophyll-a in River Ganga in the Stretch Fatehgarh to Jajmau

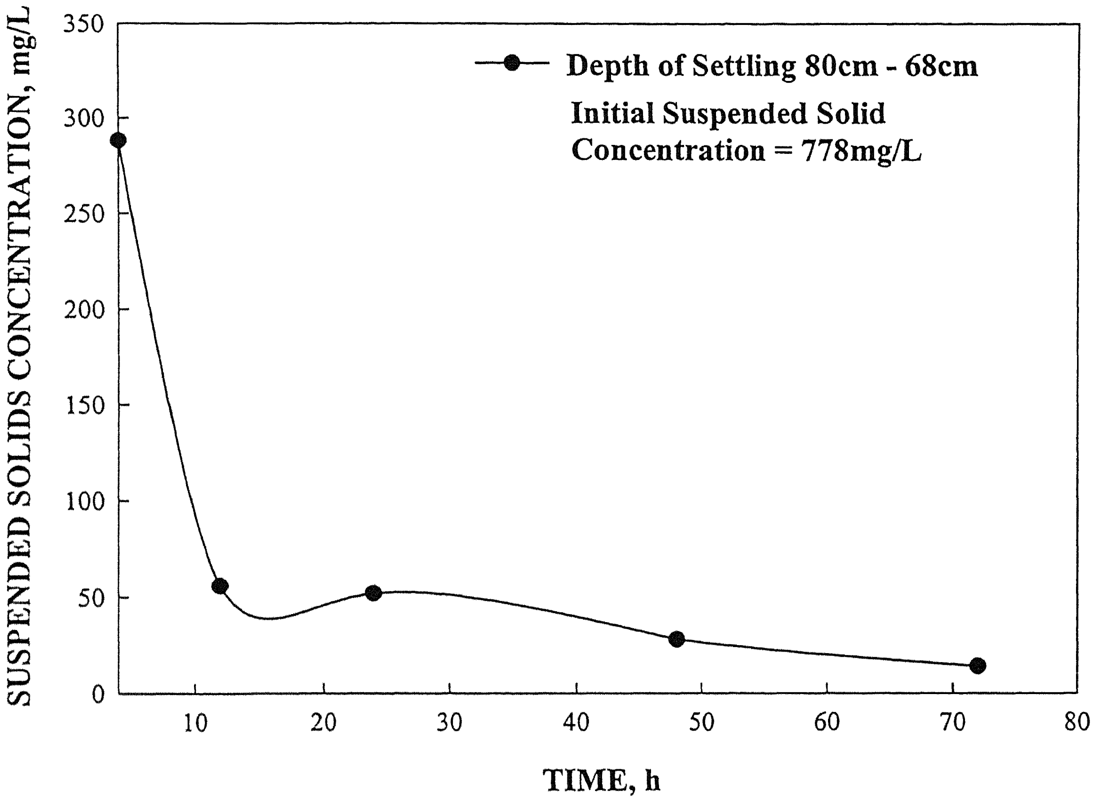


Figure 5.16 Settling Rate of Sediments of River Ganga

5.4 Impact of Mixing Anaeobically Treated Wastewaters in River Ganga

The DO levels in the down stream of Kanpur at Jajmau are considerably lower despite the reduction in BOD load and hence BOD levels (Figure 5.3) compared to that at Shuklaganj (Figure 5.2). This was thought to be due to the mixing of anaerobically treated wastewaters. As such it is necessary to study the impact of mixing such kind of wastewaters into the river Ganga. It is postulated that this may be due to the discharge of anaerobically treated wastewaters exerting instantaneous oxygen demand. Table 5.7 presents the instantaneous oxygen demand of effluents from 5 and 36 mld UASB based plants at Jajmau. The results indicate that the dip in DO levels at Jajmau may have been due to the instantaneous oxygen demand.

Table 5.7 Instantaneous Oxygen Demand of Anaerobically Treated Effluents

Location	Instantaneous Oxygen Demand, mg/L	
	Average	Standard Deviation
Outlet of 5 mld UASB Reactor at Jajmau, Kanpur	2.37	0.64
Outlet of Polishing Pond at 5 mld UASB Based Plant at Jajmau, Kanpur	1.50	0.42
Outlet of 36 mld UASB Reactor at Jajmau, Kanpur	4.58	1.07
Outlet of Post Treatment Unit at 36 mld UASB Based Plant at Jajmau, Kanpur	3.68	1.4

6 Conclusions and Recommendations

6.1 Conclusions

Based on the results of the present studies and synthesis of the available information, following conclusions may be drawn.

- BOD and DO levels in the river water have increased in the entire Kannauj – Kanpur stretch except at one of the sites, namely Jajmau at down stream of Kanpur, where a channel carrying anaerobically treated tannery and domestic wastewaters meets the river Ganga.

- Nitrogen levels in the river water appear to be increasing in the entire Kannauj – Kanpur stretch. Also increased levels of nitrite and nitrate in the river water indicate the presence of nitrifying organisms in the river.

- DO and alkalinity in the river water vary diurnally at all sites confirming the postulate that photosynthetic activity may be contributing significantly in maintaining DO levels despite increased organic loading.

- Chlorophyll-a levels and oxygen production rates due to photosynthesis appear to be positively influenced by phosphate levels in the river water. This indicates that phosphorous is the controlling nutrient for photosynthetic activity in the river.

- Chlorophyll-a levels appear to be negatively affected by ammonical and total Kjeldal nitrogen content in the river water suggesting the possibility of release of nutrient due to algal death.

- Oxygen production rates due to photosynthesis appear to be unaffected by BOD, nitrogen and turbidity levels in the river water.

- The dip in the DO levels at Jajmau in the down stream of Kanpur appears to be due to mixing of anaerobic effluents exerting high instantaneous oxygen demand instead of high organic loading as generally postulated.

6.2 Recommendations

Based on the experience gained in conducting the work reported in this thesis following recommendations are made for the logical continuation of the present work.

- Since the DO values in the river water have shown diurnal variation, any water quality monitoring programme, to assess the impact of certain intervention schemes or to compare the same at various sites or for comparison of monthly, seasonal, annual variations, etc., must ensure collection of samples at certain fixed time of the day.

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- Attempts should be made to identify the algal species at various locations in the river and relate their abundance or extinction with river water quality and importance must be given to such biological indicators in river water quality monitoring programmes.

- Detailed studies should be conducted to investigate the extent of photosynthetic activity at various sites and the river organic loading must be based on comparison of oxygen production potential due to photosynthesis and reaeration with oxygen demand rates.

- Attempts should be made to assess in detail the impact of discharging anaerobically treated wastewater into the river Ganga.

References

Agarwal, D.K., Gaur, S.D., Tiwari, I.C., Narayanswami, N. and Marwah, S.M. (1976), Physico-Chemical Characteristics of Ganges Water at Varanasi, *Ind. Jr Env. Health,* 18, 3, 201-206

Agarwal , U. (1995), Environmental Protection and Pollution Control in the Ganga, 1st Ed., M.D. Publications Ltd, Delhi, 94

Anand, P. and Agarwal, P. (2000), Impact of Action Plan Schemes and Barrage Project on River Ganga in Kanpur, BTech. Project, Department of Civil Engineering, IIT, Kanpur, India

APHA, APCF, AWWA, (1985), Standard Methods for Examination of Water and Waste Water, 16th Ed., Washington DC, USA

APHA, WEF, AWWA, (1995), Standard Methods for Examination of Water and Waste Water, 19th Ed., Washington DC, USA

Benefield, L.D. and Randall, C.W. (1980), Biological Process Design for Wastewater Treatment, Prentice Hall, Inc., Englewood Cliffs, NJ07632, 218-251

Bhargava, D.S. (1977),Water Quality in Three Typical Rivers in UP- Ganga, Yamuna and Kali, Phd. Thesis, Department of Civil Engineering, IIT, Kanpur, India

Brooks, J.L. (1971), Eutrophication and Changes in the Composition of the Zooplankton, in Eutrophication : Causes, Consequences, Correctives, Proceedings of a Symposium, NAS, Washington, 236-256

CPCB, Delhi (1991), Status and Trend of Water Quality of River Ganga (1985-89), Monitoring of Indian National Aquatic Resources Series (MINARS).

Fallowfield, (1990), Toxic Algae:Cyanobacteria, http://www.ucmp.berkeley.edu/bacteria/cyanolh.html

Forsberg, C. (1998), Which Policies can Stop Large Scale Eutrophication, *Wat. Sci. Tech.*, 37, 3, 193-200

Gerdes, P and Kunst, S. (1998), Bioavailability of Phosphorous as a Tool for Effluent P Reduction Schemes, *Wat. Sci. Tech.*, 37, 3, 241-247

Gupta, S. (2000), A Novel Approach for Assessment of Action Plan Schemes on Water Quality of River Ganga, MTech Thesis, Environmental Engineering and Management Programme, IIT, Kanpur, India.

Johnson, R.A. (1994), Probability and Statistics for Engineers, 5th Ed., PHI, Delhi, 397.

Kashiprasad (1977), Survival of Coliform Organism in River Ganga Water Near Kanpur and Applicability of Water Quality Indices, M.Tech.Thesis, Department of Civil Engineering, IIT, Kanpur, India.

Ketchum, B.H., (1954), Mineral Nutrition of Phytoplankton, *Ann. Rev Plant Physiol*, 5, 55-74

Khanna , D.R..(1993), Ecology and Pollution of Ganga River, 1st Ed., APH, Delhi.,85-103

Krauss, W.R. (1953), Inorganic Nutrition of Algae in the Algal Culture Laboratory to Pilot Plant, (Carnegie Institution of Washington, No.600, Edited by J.Burlew), 85-102.

Laxminarayan, J.S.S, (1965), Studies on the Phytoplankton of the River Ganga, *Hydrobiologia*, 25(1-2), 119-175.

Lijklema, L., (1995), Development and Eutrophication: Experiences and Perspectives, *Wat. Sci. Tech.*, 31, 9, 11-15

NRCD (1999), *Bulletin for Water Quality Monitoring and Performance of Sewage Treatment Plants*, Ministry of Environment and Forests, Government of India, New Delhi.

Pavoni, J.L, Tenny, M.W. and Escelberger Jr.,W.F., (1972), Bacterial Exocellular Polymers and Biological Flocculation, *Jr. of Water Pollution Control Federation*, 44, 3, 414

Rosensteel, A.B. and Strom, P.F. (1991), River Phosphorous Dynamics and Reservoir Eutrophication Potential, *Wat. Res. Bulletin*, 27, 6, 957-965

Sabata, B.C. and Nayar, N.P., (1990), River Pollution in India – A Case Study of Ganga River, 1stEd., APH Publishing Corpn., Delhi, 13, 136-153

Saxena, K.L., Chakrabarty, R.N., Khan,A.Q., Chattopadhya, S.N. and Chandra, H. (1966), Pollution Studies of the River Ganga Near Kanpur, *Environmental Health*, 8, 270-285

Shrihari, S. (1999), Effects of Benthal Sludge on Overlying Water, Phd.Thesis, Department of Civil Engineering, University of Roorkee, Roorkee, India.

Shukla, A.C. and Agarwal, V. (1995), Ganga: A Water Marvel, 1st Ed., APH, Delhi, 219, 223, 147-163

Tare,V. (1997), Water Quality Monitoring of River Ganga (in the Kannauj u/s - Kanpur d/s Stretch) and Monitoring of 5 and 36 MLD UASB Plants at Kanpur and Oxidation

Pond at Farrukhabad, Annual Report Submitted to National River Conservation Directorate, Delhi.

Tare,V. (1998), Water Quality Monitoring of River Ganga (in the Kannauj u/s - Kanpur d/s Stretch) and Monitoring of 5 and 36 MLD UASB Plants at Kanpur and Oxidation Pond at Farrukhabad, Annual Report Submitted to National River Conservation Directorate, Delhi.

Tare,V. (1999), Water Quality Monitoring of River Ganga (in the Kannauj u/s - Kanpur d/s Stretch) and Monitoring of 5 and 36 MLD UASB Plants at Kanpur and Oxidation Pond at Farrukhabad, Annual Report Submitted to National River Conservation Directorate, Delhi.

Thompson, J.F. and Morrison, G.R. (1951), Determination of Organic Nitrogen, *Analytical Chemistry*, 23, 1153-1157

Uhlmann, D. (1979), Hydrobiology, 1st Ed., John Wiley & Sons, New York, 25-77

Wine, R.L. (1966), Statistics for Scientists and Engineers, 1st Ed. Prentice Hall of India, New Delhi, 311-315.